NATIONAL STEEL AND SHIPBUILDING COMPANY

LEAPFROG TECHNOLOGY TO STANDARDIZE EQUIPMENT AND SYSTEM INSTALLATIONS

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1) Typical Ship Specification
2) AISC Steel Design Manual, Ninth Edition
3) Blodgett, "Design of Welded Steel Structures"
4) NASSCO Guidelines for Commercial Foundation Drawings, Section 11. 1
5) Bruhn, "Analysis and Design of Flight Vehicle Structures", p.D1.5-D1.6

INTRODUCTION

The grillage is the simplest and most common type of foundation. Therefore, where it is not possible to mount equipment with weld studs or spools, the greatest cost savings can be achieved by standardizing a producible grillage design. In the past, grillages have typically consisted of two or more parallel spans of angle iron welded continuously along their length to either deck or bulkhead plating or spanning between deck or bulkhead stiffeners. This is an inefficient method of installation because it typically involves a large amount of welding and fitting. Considering the number of grillages mounting light weight equipment aboard a ship, great cost savings can be achieved by instead lifting grillage angles up off of plating and stiffeners with chocks which attach the web of the angle to supporting ship structure. This practice reduces the amount of required welding and simplifies the foundation assembly.

Additional savings can be achieved if this grillage is then mounted directly to soft plating or cantilevered off of stiffeners, where these practices are feasible. Previous practice unnecessarily avoided landing on soft plate or cantilevering, and grillages were almost always bridged to rigid ship structure, even though this is typically not necessary with lighter equipments. By obviating this old convention, significant cost savings are generated by eliminating the pieces associated with bridging the foundation to ship structure. This greatly reduces the welding, cutting and fit-up time associated with a particular foundation.

The intention of this grillage study is to provide design guidance in terms of allowable equipment weight for grillages simply supported between chocks, cantilevered off of stiffeners and/or attached directly to soft plate. This guide is in the for m- of allowable weight curves where the allowable equipment weight is dependent on the length of span between chocks, the size of the angle used, the thickness of the ship plating and the ratio of the eccentricity of the equipment center of gravity to the distance between opposing bolts (e/h). So for a given piece of equipment and mounting location, the designer can choose the appropriate angle size based on the most producible mounting condition. Families of allowable curves were produced for both the simply supported chock mounted grillage and the cantilevered grillage using the following angle sizes: 2"×2"×3/16"; 2"×2"×1/4"; 2"×2"×3/8"; 2-1/2"×2-1/2"×3 /8"; 3"×3"×3/16"; 3"×3"×¼"; 3"×3"×3/8"; 3"×3"×1/2"; 4"×4"× 3/8" ; 4"×4"×½"; 4"×4"× ¾"; 6"×4×3/8" ; 6"×4"×½"; 6"×4"×¾". Another set of allowable curves was created for the landing of grillages on soft plate. This set of allowables is based on the thickness of the plate and provides guidance for plate thicknesses from 3/16" to 11/16".

METHOD OF ANALYSIS

Allowable weight for a given grillage configuration is determined based on a number of different failure criteria, all of which fall into two categories, strength criteria and frequency criteria. Spreadsheets were created which calculate the weight limits based on each criteria for a large envelope of grillage configurations. For each configuration, the lowest allowable weight from the most limiting criteria is used for that specific grillage. The allowables for each of these criteria is calculated using conservative methods, loads, and assumptions as outlined in the following.

GRILLAGE CONFIGURATIONS

Two different types of grillage configurations are considered in this study: grillages in which the spans are simply supported by chocks or structural stiffeners, and grillages where the angles are cantilevered off of ship structure. It is assumed that each of these two configurations consist of one or more sets of spans, where a span consists of two parallel pieces of angle. In reality a span may have more than two parallel angles, but in analysis it is conservative to use two to encompass all possibilities. For each configuration type, a worst case loading scenario is assumed which envelops all possible mountings on that grillage. That is, for the two grillage types, the load induced at an individual bolt and on the angle will be the highest load that any feasible configuration will produce.

SIMPLY SUPPORTED GRILLAGE CONFIGURATION

For the case of a grillage spanning between chocks or stiffeners, the worst condition will be the one which places a maximum bolt load on the middle of the angle. This case produces the maximum bending moment in the angle and the lowest natural frequency for the system. An example where this type of loading would occur would be a grillage supporting equipment with only two bolts, where the bolts land on the middle of the span (*see Figure 7-1 — Worst Simply Supported Grillage Configuration*). Another example would be a grillage supporting equipment with a narrow footprint; i.e. the bolts are very close together.

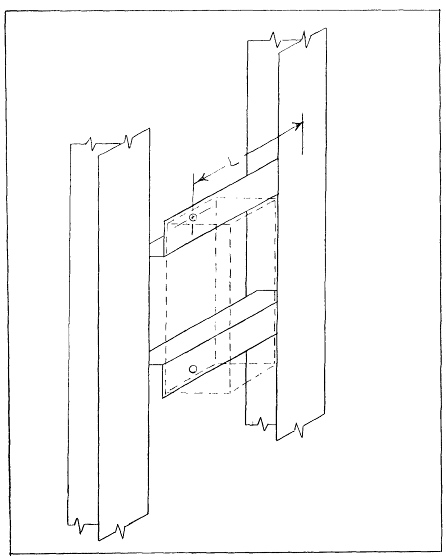


Figure 7-1 — Worst Simply Supported Grillage Configuration

CANTILEVER GRILLAGE CONFIGURATION

Similar to the simply supported grillage, the worst case for the cantilevered grillage is the one which produces the highest bending moment and lowest frequency. This is the condition where the equipment bolts land near the end of the cantilevered angles and the equipment itself does not support any moment. This will occur with equipments with narrow footprints, or bolting patterns in which only two of the bolts land on the cantilevered portion of the foundation (see *Figure 7-1 — Worst Cantilevered Grillage Configuration*).

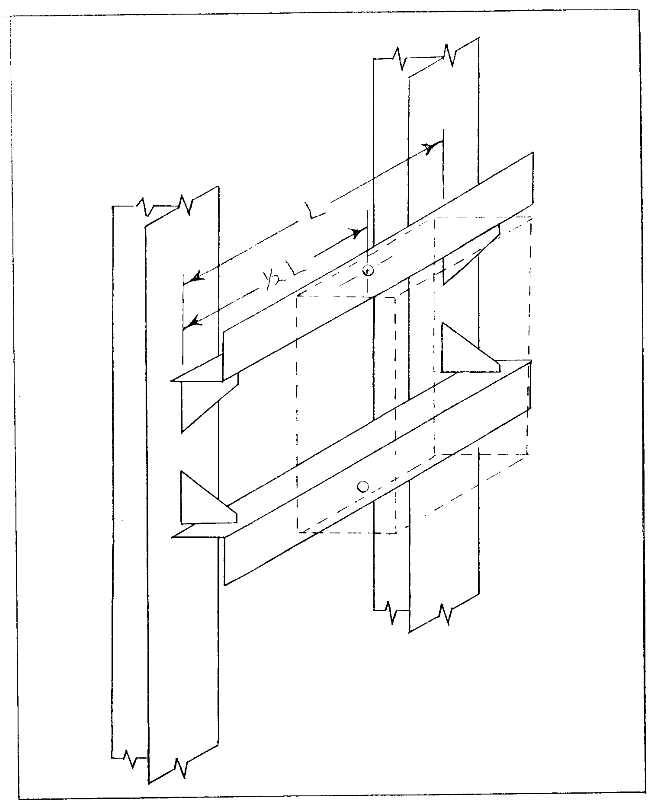


Figure 7-1 — Worst Cantilevered Grillage Configuration

LOADS

Loads are induced into grillage angles through the equipment bolts. Ship's motion loads on the equipment, measured in terms of equivalent static g's, are applied to the equipment and resultant forces are resolved at the bolts. Acceleration values, based on a worst case ship location, of 2.5 g's vertical, 1.25 g's transverse and 0.5 g's longitudinal are applied to the equipment simultaneously (see *Section 5, Appendix A* for calculations). Combined with the equipment weight, these accelerations produce forces on the equipment acting in all three directions. From this equipment load, forces are resolved on the grillage based on the assumed worst case configurations.

In calculating resultant forces the number of bolts on a span is not considered, instead a worst case assumption is made that each angle of a span has only two effective bolts. For example, axial and shear forces are computed as if there is only one bolt on either angle of a grillage span. Overturning forces are computed based on the e/h of the equipment and distributed on the grillage spans as if they are supported by only one bolt. Since forces are acting in three directions, there are two directions which produce overturning forces and in reality two different equipment e/h's to consider, but to be conservative the minimum of the two values, producing the higher resultant force for a given load, is used for both directions of overturning.

Additionally, the worst conceivable load at a bolt is calculated by orienting the grillage so that the ship's motion loads produce the highest bolt loads. For equipments with high e/h values, this is when the grillage and equipment are oriented such that the largest g's from vertical ship's motions produce overturning loads at the bolts. Grillages on a bulkhead have this type of overturning orientation. For equipments with low e/h values, the worst grillage orientation is when the equipment sits on the deck and the high vertical force acts perpendicular to the plane of the grillage, inducing axial bolt loads. *Figure 7-1 — Resolving of Grillage Forces* shows how the loads from a typical grillage orientation and bolt pattern are conservatively approximated.

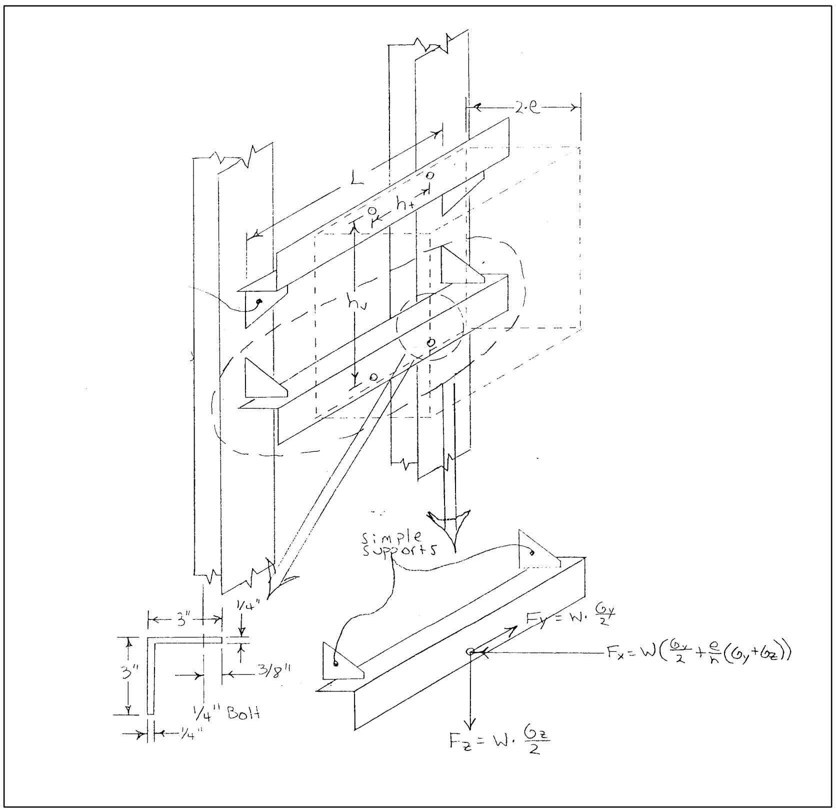


Figure 7-1 — Resolving of Grillage Forces

FAILURE CRITERIA

STRENGTH

Based on the above configurations and loads, stresses are computed for all possible failure modes. Failure is assumed to occur through yield failure in one or both of the angles, or by local yield failure in way of one or more bolts. All stresses are computed at their worst location, the spot on the grillage where the biggest force or moment occurs. The formulas used for computing different stresses are conservative, previously approved methods.

Angle stresses are calculated using beam formulas. Critical stress occurs in an angle as a result of both bending and axial loads in the beam. Bending stress is nominal, calculated based on the maximum moment and the elastic section modulus of the most extreme fibers. Bending stresses are combined for biaxial bending, where the stress at the toe of the angle from one direction of bending is added to the stress at the heel from the other direction of bending and vice-versa. This worst bending stress is then combined with the nominal axial stress calculated from the highest axial load in a grillage angle and the cross-sectional area of the angle. This maximum combined beam stress is the value used to check the integrity of the grillage angles.

Bolt attachment is checked for all modes of shear, bearing and bending. All calculations are performed assuming ¼" bolts, since this is the smallest bolt used by NASSCO (Reference 4), and smaller bolts produce higher stresses for all failure modes. Shear failure can either occur perpendicular to the angle flange due to axial bolt loads or parallel to the flange from shear loads in the bolt. Bearing stress is a nominal stress computed from the cross-sectional area of the bolt hole. Figure 4 shows all possible flange failure modes, and Appendix B provides the rationale for the calculation methods used in computing the nominal stresses.

Flange bending is the result of the moment created between the centerline of a bolt and the heel of the angle. The greater the bolt distance from the heel, the greater the flange bending moment. So to be conservative, the bolt is assumed to land at its furthest possible location from the heel, which according to NASSCO’s Drafting Guide (Reference 4), is 3/8” from the toe of the angle for a ¼” bolt. The moment produced is resisted partially at the bolt and partially at the angle heel depending on the condition of fixity at those locations. Stresses are always critical at the location of the bolt since the effective section of the angle is much less in way of the point fixity at the bolt than along the line of fixity at the heel. Therefore, the conservative assumption is made that the equipment is always clamped to the flange at the bolt, and the amount of moment taken at the bolt is dependent on the condition of fixity at the heel. Curves are created for three cases of flange bending: partially free at the heel, fully fixed at the heel, and no flange bending possible. No flange bending possible is the case where the flange of the angle is prevented from bending by added structure, such as chocks which connect the flange directly to ship structure in way of the bolt. The remaining two cases distribute the moment on the flange differently. The fully fixed case places half the moment at the bolt and half at the heel, the partially fixed case puts eighty percent of the moment at the bolt and twenty percent at the heel. On a grillage this difference is the result of different fixities at the heel. For example, an angle with a chock welded to the heel of the angle in way of the bolt would be considered fully fixed, while an angle without the chock is considered to be partially fixed. The rationale for the calculation methods used appears in *Section 5, Appendix B* of this report.

FREQUENCY

An important criteria for all structure is the value of its natural frequency of vibration in relation to the frequency of any exciting forces on that structure. For grillages, it is therefore important to insure that the lowest natural frequency of vibration of the grillage is greater than the excitation frequency of the propeller. The natural frequency is checked for several modes of vibration, and the lowest natural frequency of the grillage is compared to the allowable frequency. These checks are made for the worst case grillage configurations described previously. Springs included in the natural frequency calculation for a grillage are the bending of the angle, in two directions, and the flexibility of the flange. Torsional flexibility of the angles is disregarded because of the assumption that the flange is clamped to the equipment, meaning that the moment normally taken torsionally by the angle is instead resisted by the equipment. These two springs are coupled in series to determine the stiffness and subsequent natural frequency of the grillage for three different vibration modes. Natural frequency is calculated for vibration of the grillage parallel to its plane, perpendicular to its plane and due to overturning motion of the equipment. The mode which results in the lowest natural frequency is the one which governs the acceptability of the grillage.

When a grillage does not land on rigid ship structure, such as stiffeners or back up structure, it is necessary to check the natural frequency of the grillage coupled with the vibration of the soft plate. However it is no longer necessary to include the angle as a spring in this calculation because when a grillage is landed on soft plate the corner bolts of the equipment fall at the extreme ends of the grillage in way of the chocks. The springs for this natural frequency calculation are thus the flange flexibility and the out-of-plane soft plate bending. Natural frequency is calculated based on these series springs for the perpendicular and overturning modes of vibration.

ALLOWABLES

STRESS

Maximum allowable stress for any failure mode is set at a value which precludes yielding of the angle. Considering that the loading and orientation of the grillage and bolting are very conservative, the material allowable is taken as eighty percent (80%) of the 0.2 material static yield strength. This is the allowable for nominal tensile stress. For nominal shear and bearing stress, a percentage reduction is taken on the tensile allowable to reflect steel's capacity for carrying those types of loads. Shear is taken as sixty percent of the tensile allowable and the bearing allowable is set at eighty percent of the tensile allowable. Given that the foundations for the Sealift ships are to be constructed of mild steel with a yield strength of thirty-four thousand psi (34 ksi), the allowable tensile stress is 27.2 ksi, the allowable shear stress is 16.32 ksi, and the allowable bearing stress is 21.76 ksi.

FREQUENCY

Based on the propeller rpm and number of blades of the Sealift new construction ships, the allowable natural frequency for a grillage is twelve Hertz (12 Hz). This frequency is 1.25 times the excitation frequency of the propeller. It must be insured that the natural frequency of any grillage, be it coupled with soft plate or not, is equal to or greater than this number.

RESULTS

The results of this study is a collection of graphs and tables which provide the allowable weight on a grillage span based on the type of grillage (simply supported or cantilevered), angle size, length of unsupported span, e/h of the equipment, type of flange bending and thickness of soft plate, where applicable. These tables and graphs were created by performing tabular calculations on all the different grillage configurations. These calculations were performed using the assumptions, techniques, and allowables described in the above sections. A sample of these spreadsheet calculations outlining the specific formulas and methods of analysis appears in *Section 5, Appendix C*.

SIMPLY SUPPORTED AND CANTILEVERED GRILLAGE RESULTS

For simply supported and cantilevered grillages, a different graph is generated for each flange bending condition and e/h value studied. The flange bending conditions are no bolt chocks (partially fixed at the heel), bolt chocks (fully fixed at the heel), and no flange bending possible (the flange is restrained from bending). Three different e/h values are examined: e/h equals 1.5, 1.0, and 0.5. Since there are two variables each with three possibilities, there are a total of nine graphs for both the simply supported and cantilevered conditions, or a grand total of eighteen graphs. Each graph plots the length of unsupported span versus the allowable equipment weight for that length of span. The length of span for a simply supported grillage is the distance between adjacent chocks which lift a grillage angle up off of ship structure or the distance between stiffeners to which the grillage angles are welded. For a cantilevered grillage, the length of unsupported span is the distance from the support of the cantilevered angle to the bolt furthest out on the angle. A different curve is plotted for the following fourteen angle sizes studied:

2"×2"×3/16"	2"×2"×1/4"	2"×2"×3/8"	2-1/2"×2-1/2"×3/8"	3"×3"×3/16"	3"×3"×1/4"
3"×3"×3/8"	3"×3"×1/2"	4"×4"×3/8"	4"×4"×1/2"	4"×4"×3/4"	6"×4"×3/8"
6"×4"×1/2"	6"×4"×3/4"				

Thus, these eighteen graphs encompass a large envelope of grillage possibilities and provide allowables which encompass all potential failure modes. These graphs and supporting tables follow in the sections labeled *Simply Supported Grillage Results* and *Cantilevered Grillage Results*.

SOFT PLATE RESULTS

A different set of curves was developed for allowable equipment weights based on landing grillages on soft plate. Similar to the curves for landing on ship structure, a different curve is developed for each angle size. However the allowable is based on the thickness of the plate, instead of the length of the span. Calculations were performed for plate thicknesses from 3 /16" to "1,611 at '/,601 increments. There are a total of nine plots, one for each e/h and flange bending condition examined. These graphs and supporting tables follow in the section labeled *Soft Plate Results*.

SIMPLY SUPPORTED GRILLAGE RESULTS

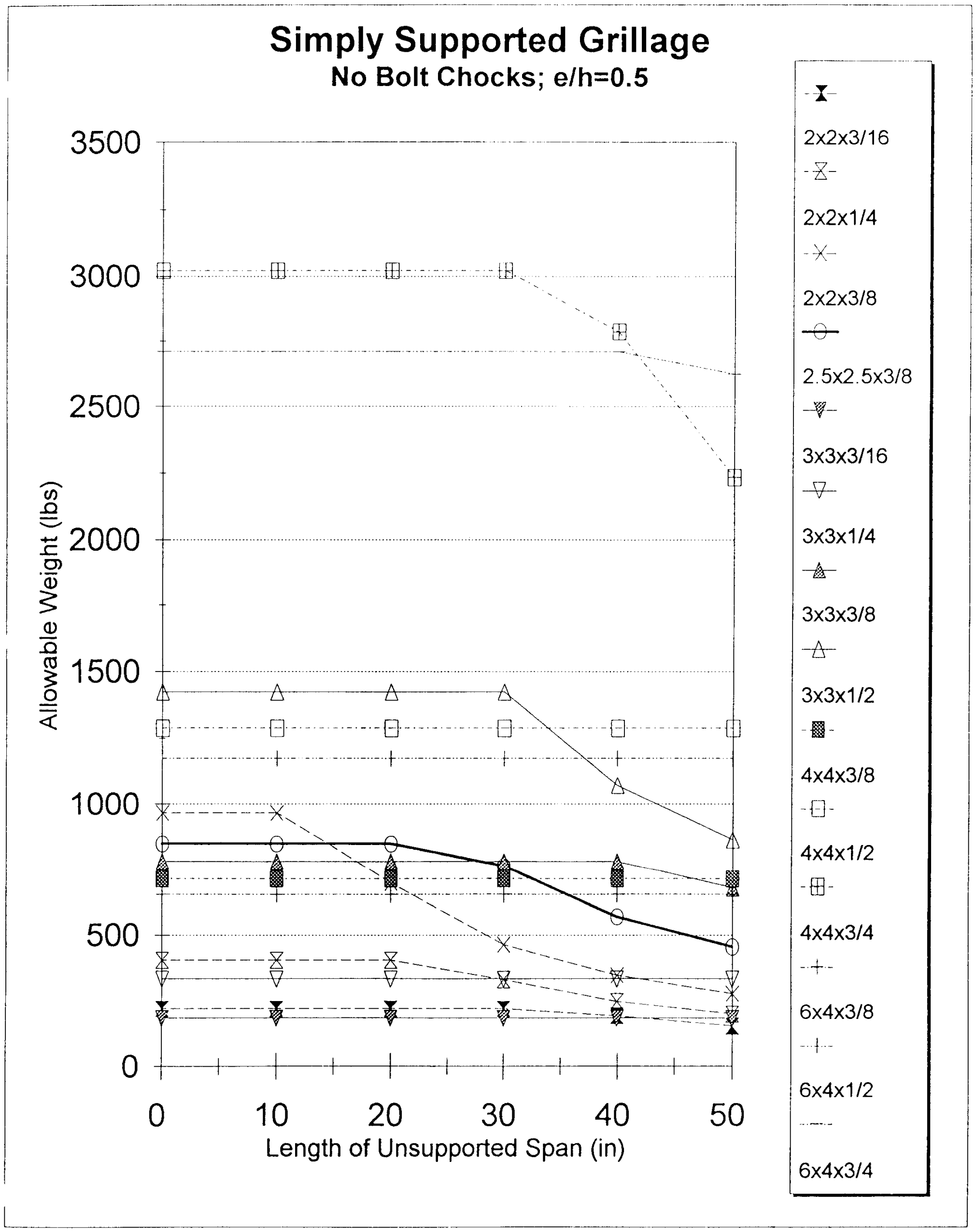


Figure 7-1 — Simply Supported Grillage, No Bolt Chocks; e/h = 0.5

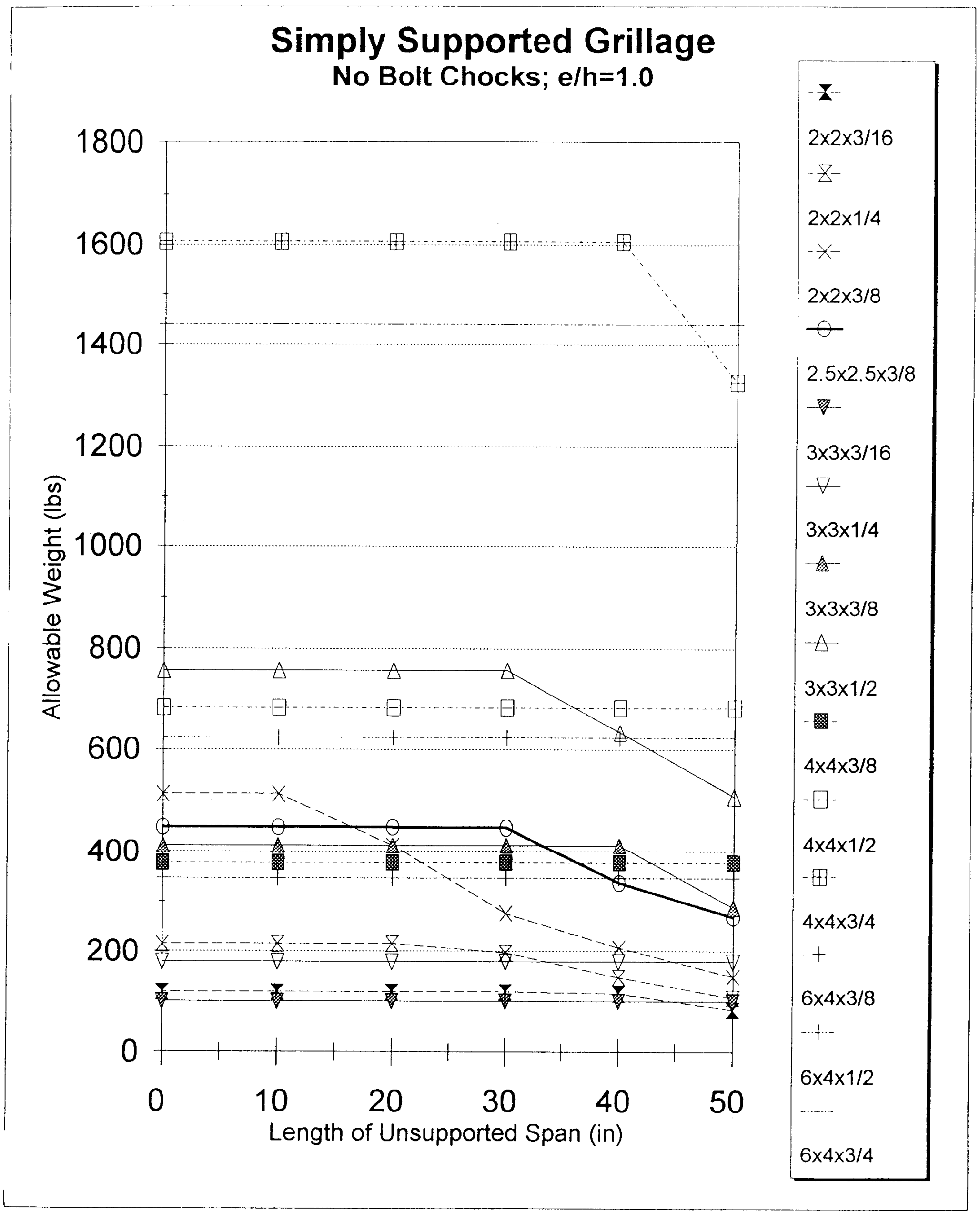


Figure 7-2 — Simply Supported Grillage, No Bolt Chocks; e/h = 1.0

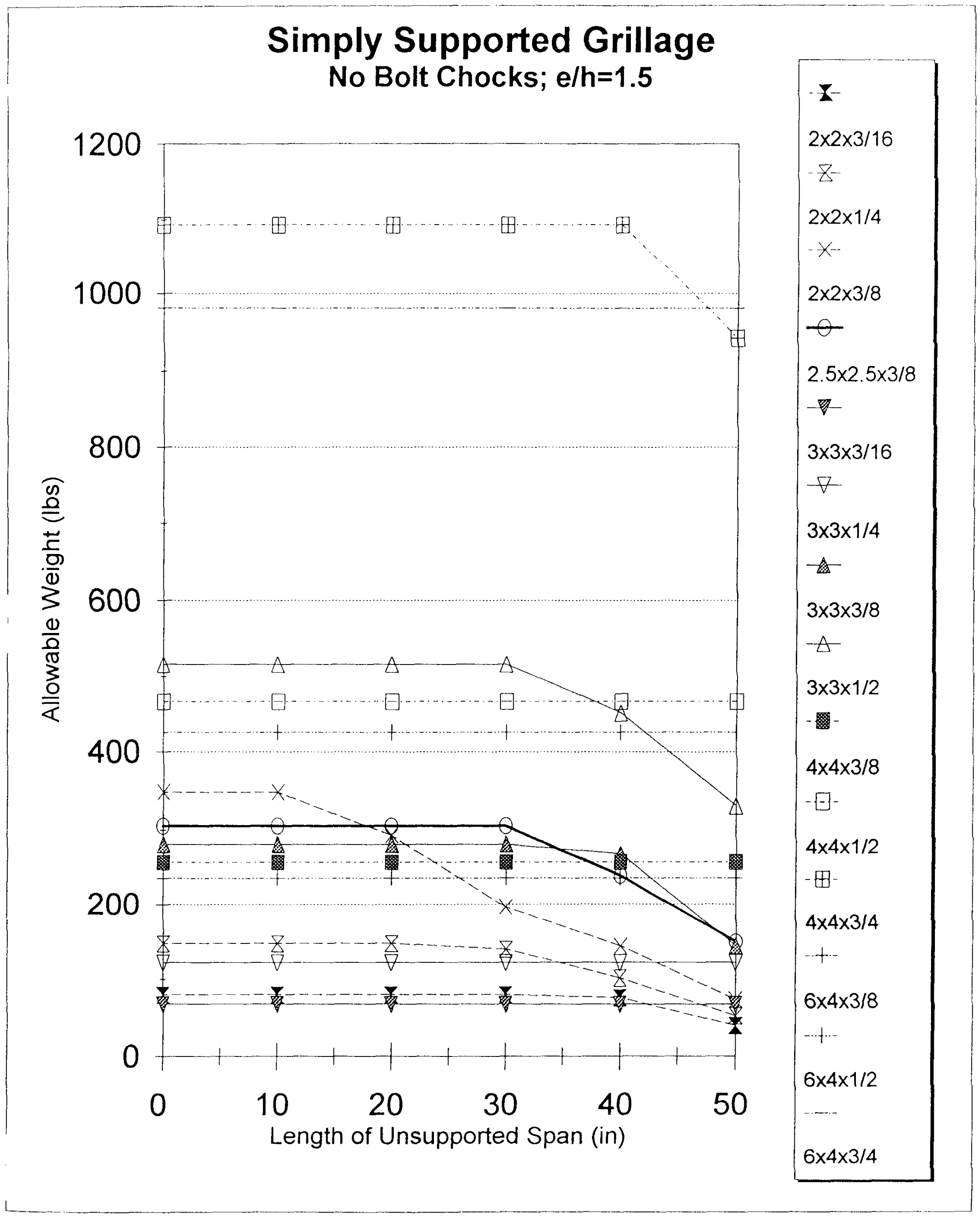


Figure 7-3 — Simply Supported Grillage, No Bolt Chocks; e/h = 1.5

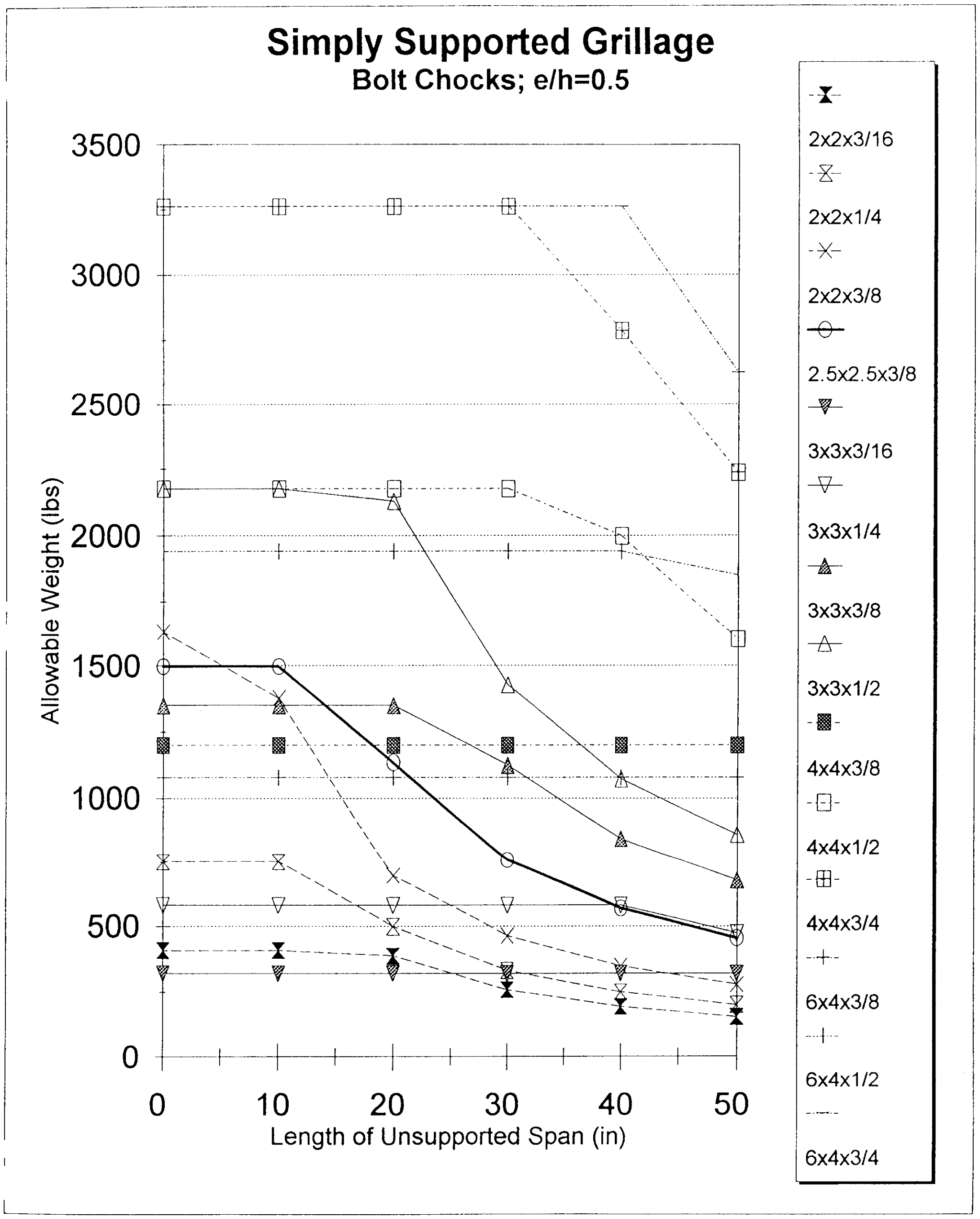


Figure 7-4 — Simply Supported Grillage, Bolt Chocks; e/h = 0.5

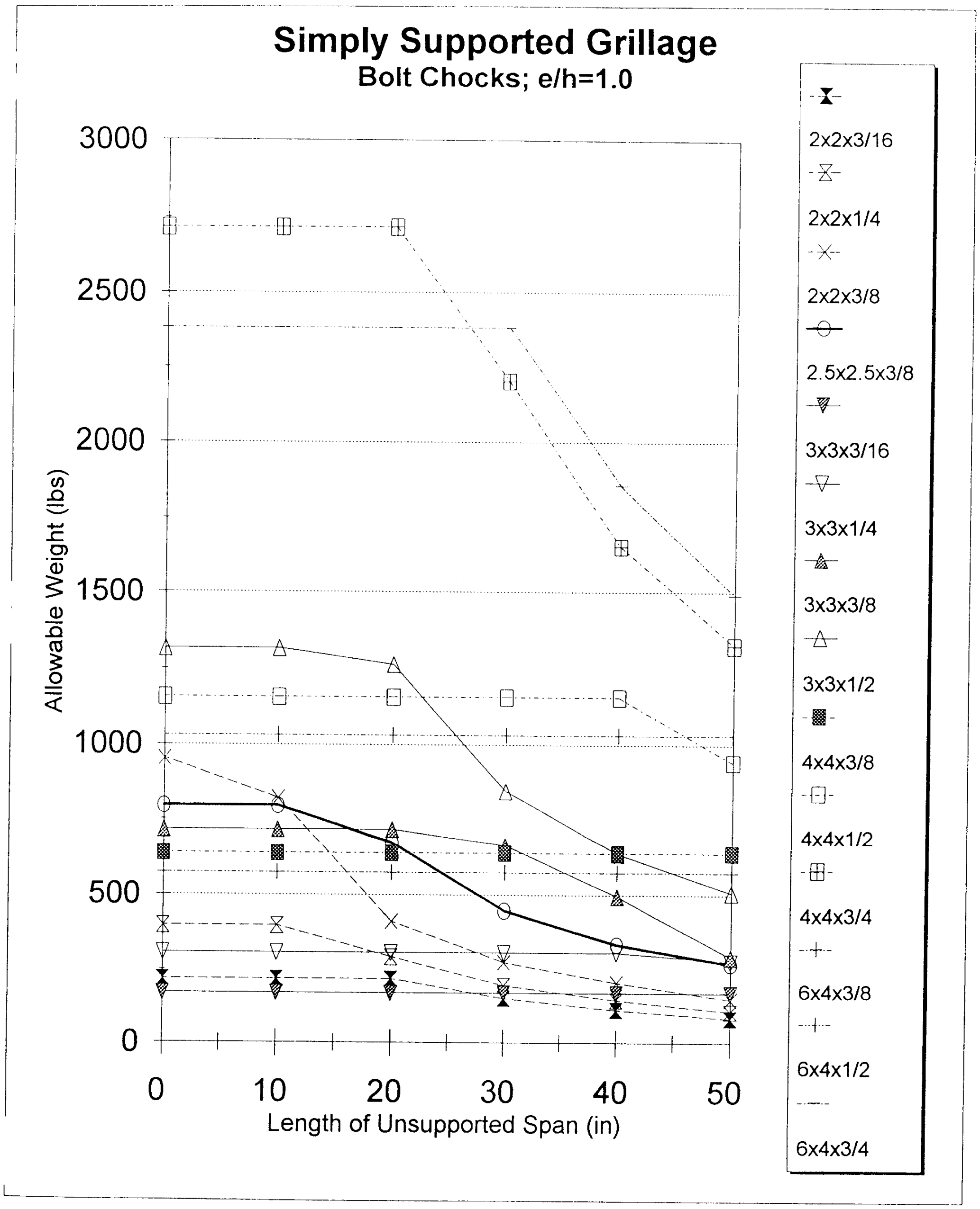


Figure 7-5 —Simply Supported Grillage, Bolt Chocks; e/h = 1.0

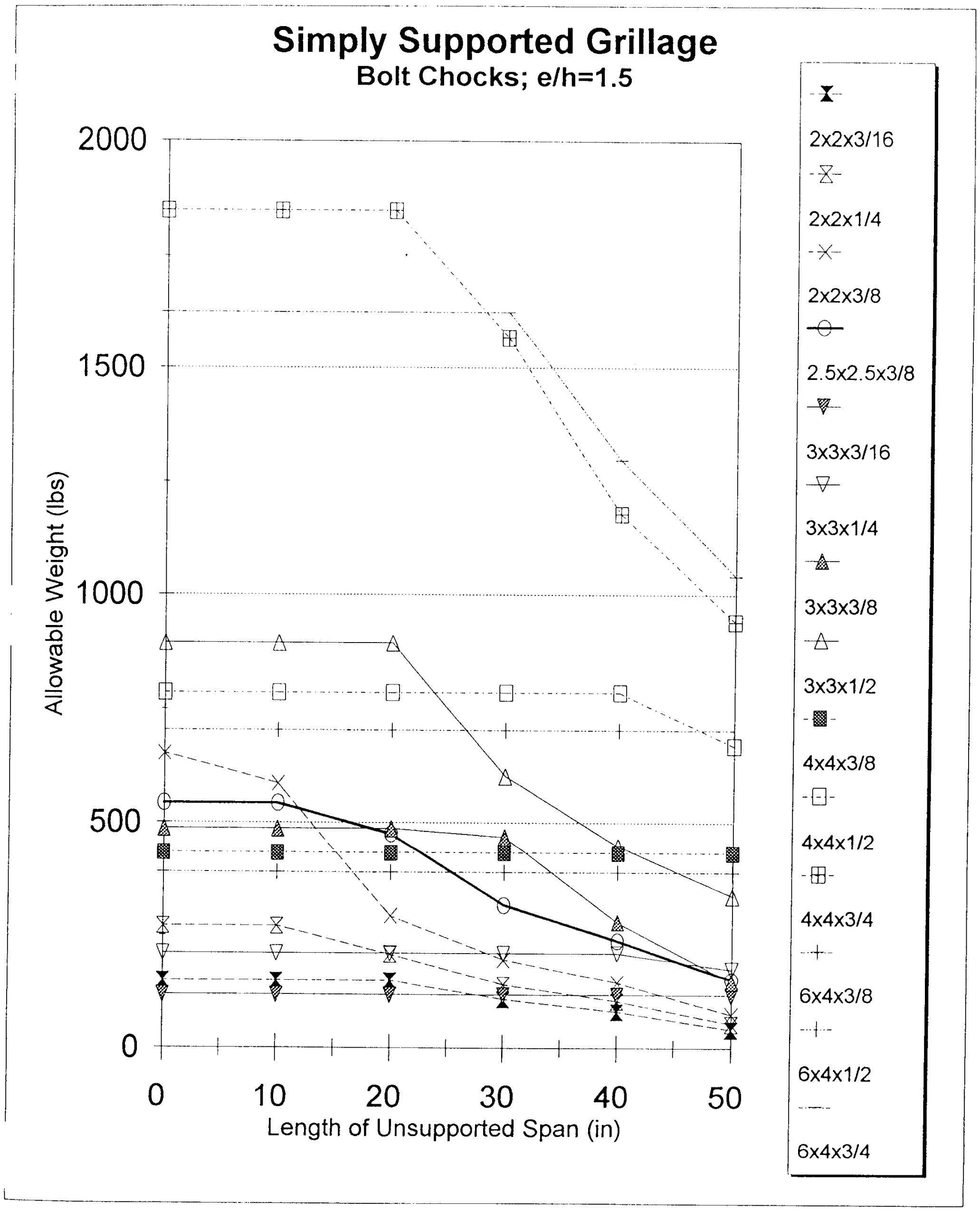


Figure 7-6 — Simply Supported Grillage, Bolt Chocks; e/h = 1.5

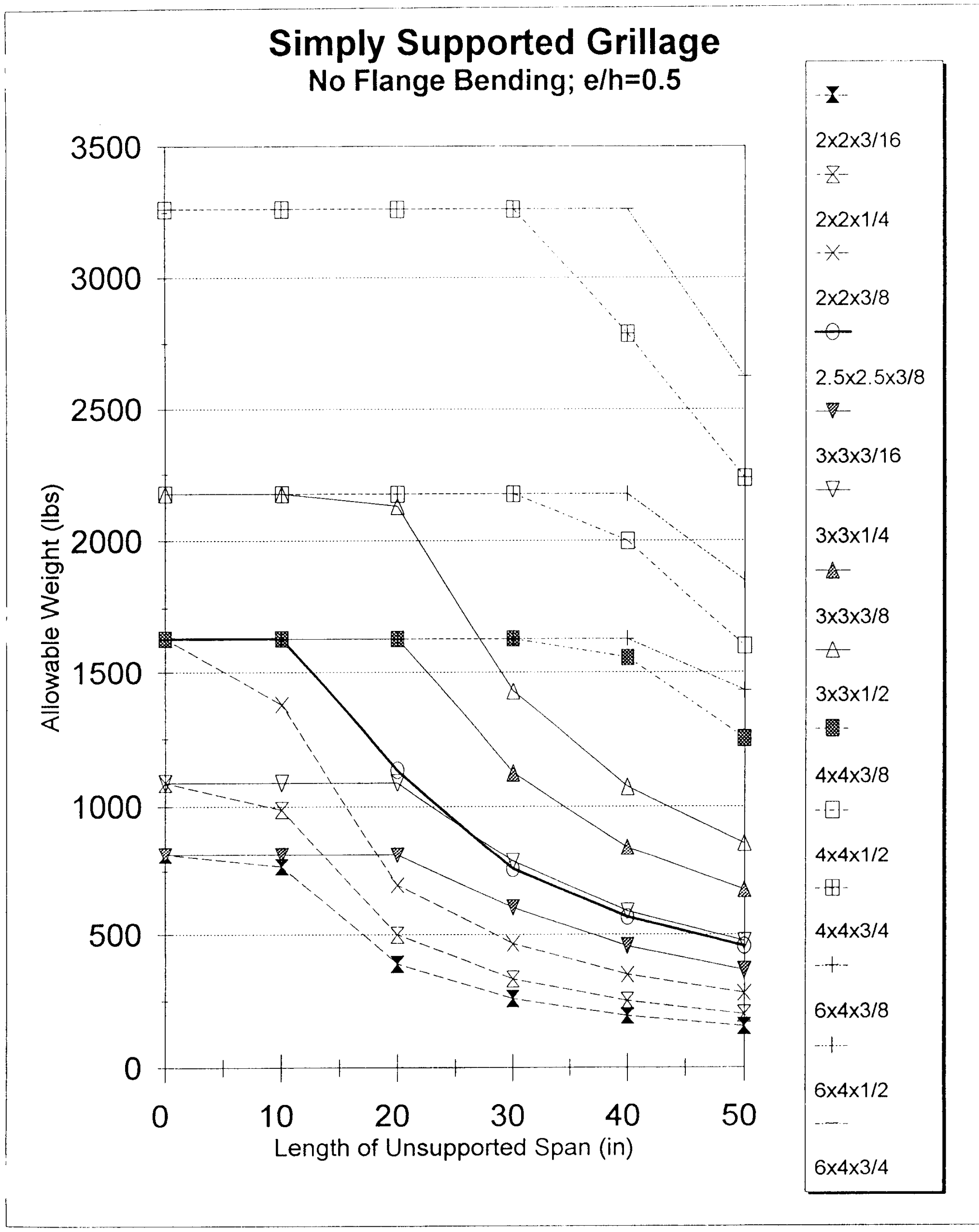


Figure 7-7 — Simply Supported Grillage, No Flange Bending; e/h = 0.5

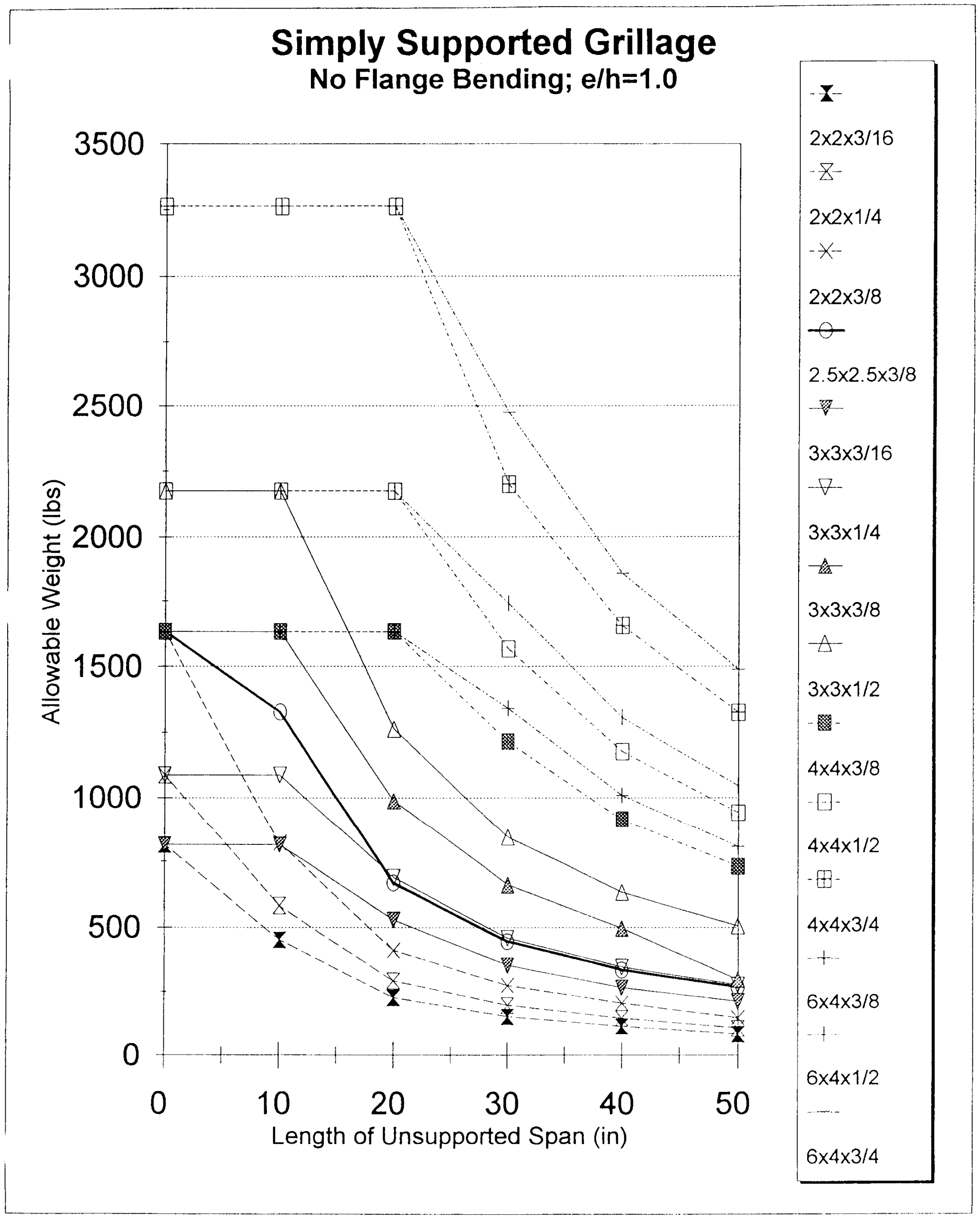


Figure 7-8 — Simply Supported Grillage, No Flange Bending; e/h = 1.0

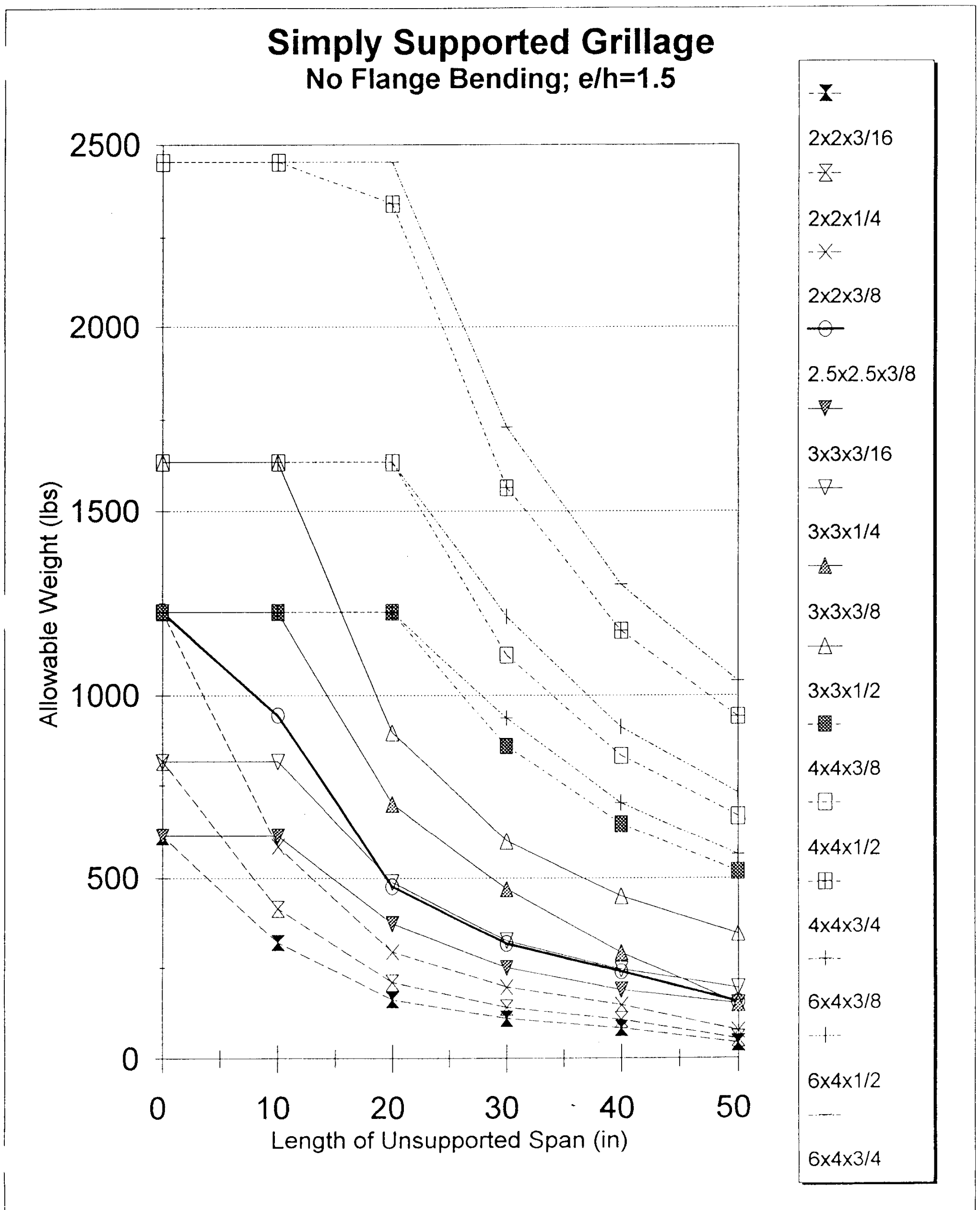


Figure 7-9 — Simply Supported Grillage, No Flange Bending; e/h = 1.5

ALLOWABLE GRILLAGE WEIGHTS — GRILLAGE WITH SIMPLY SUPPORTED SPANS — NO BOLT CHOCKS (ALLOWABLE WEIGHT IN LBS.)

	2×2×3/16			2×2×¼			2×2×3/8			2.5×2.5×3/8		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	224	119	81	408	217	147	966	513	350	845	449	306
10	224	119	81	408	217	147	966	513	350	845	449	306
20	224	119	81	408	217	147	697	414	294	845	449	306
30	224	119	81	335	197	139	467	277	197	760	449	306
40	196	115	77	252	148	102	351	208	144	572	337	239
50	157	82	41	202	107	53	281	149	74	458	270	149

	3×3×3/16			3×3×¼			3×3×3/8			3×3×½		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	224	119	81	408	217	147	966	513	350	845	449	306
10	224	119	81	408	217	147	966	513	350	845	449	306
20	224	119	81	408	217	147	697	414	294	845	449	306
30	224	119	81	335	197	139	467	277	197	760	449	306
40	196	115	77	252	148	102	351	208	144	572	337	239
50	157	82	41	202	107	53	281	149	74	458	270	149

	4×4×3/8			4×4×½			4×4×3/8		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	711	378	257	1290	685	466	3024	1606	1094
10	711	378	257	1290	685	466	3024	1606	1094
20	711	378	257	1290	685	466	3024	1606	1094
30	711	378	257	1290	685	466	3024	1606	1094
40	711	378	257	1290	685	466	2789	1606	1094
50	711	378	257	1290	685	466	2237	1327	943

	6×4×3/8			6×4×½			6×4×3/4		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	654	347	236	1176	625	425	2713	1441	981
10	654	347	236	1176	625	425	2713	1441	981
20	654	347	236	1176	625	425	2713	1441	981
30	654	347	236	1176	625	425	2713	1441	981
40	654	347	236	1176	625	425	2713	1441	981
50	654	347	236	1176	625	425	2626	1441	981

Allowable Grillage WEIGHTS — Grillage With Simply SuppoRTED Spans — Bolt Chocks (Allowable Weight in Lbs.)

	2×2×3/16			2×2×¼			2×2×3/8			2.5×2.5×3/8		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	411	219	149	753	400	272	1632	956	651	1500	797	543
10	411	219	149	753	400	272	1378	822	586	1500	797	543
20	390	219	149	500	295	209	697	414	294	1135	671	476
30	261	153	108	335	197	139	467	277	197	760	449	318
40	196	115	80	252	148	104	351	208	145	572	337	239
50	157	84	42	202	108	54	281	149	75	458	270	152

	3×3×3/16			3×3×¼			3×3×3/8			3×3×½		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	322	171	117	582	309	210	1350	717	488	2176	1316	896
10	322	171	117	582	309	210	1350	717	488	2176	1316	896
20	322	171	117	582	309	210	1350	717	488	2130	1264	896
30	322	171	117	582	309	210	1126	663	470	1429	846	601
40	322	171	117	582	309	210	847	498	281	1075	635	451
50	322	171	117	477	278	176	679	295	147	861	509	339

	4×4×3/8			4×4×½			4×4×¾		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	1200	638	434	2176	1157	788	3264	2720	1852
10	1200	638	434	2176	1157	788	3264	2720	1852
20	1200	638	434	2176	1157	788	3264	2720	1852
30	1200	638	434	2176	1157	788	3264	2203	1567
40	1200	638	434	2002	1157	788	2789	1656	1177
50	1200	638	434	1605	944	669	2237	1327	943

	6×4×3/8			6×4×½			6×4×3/4		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	1080	574	391	1944	1033	703	3264	2384	1623
10	1080	574	391	1944	1033	703	3264	2384	1623
20	1080	574	391	1944	1033	703	3264	2384	1623
30	1080	574	391	1944	1033	703	3264	2384	1623
40	1080	574	391	1944	1033	703	3264	1861	1300
50	1080	574	391	1853	1033	703	2626	1491	1041

Allowable Grillage WEIGHTS — Grillage With Simply SuppoRTED Spans — no flange bending (Allowable Weight in Lbs.)

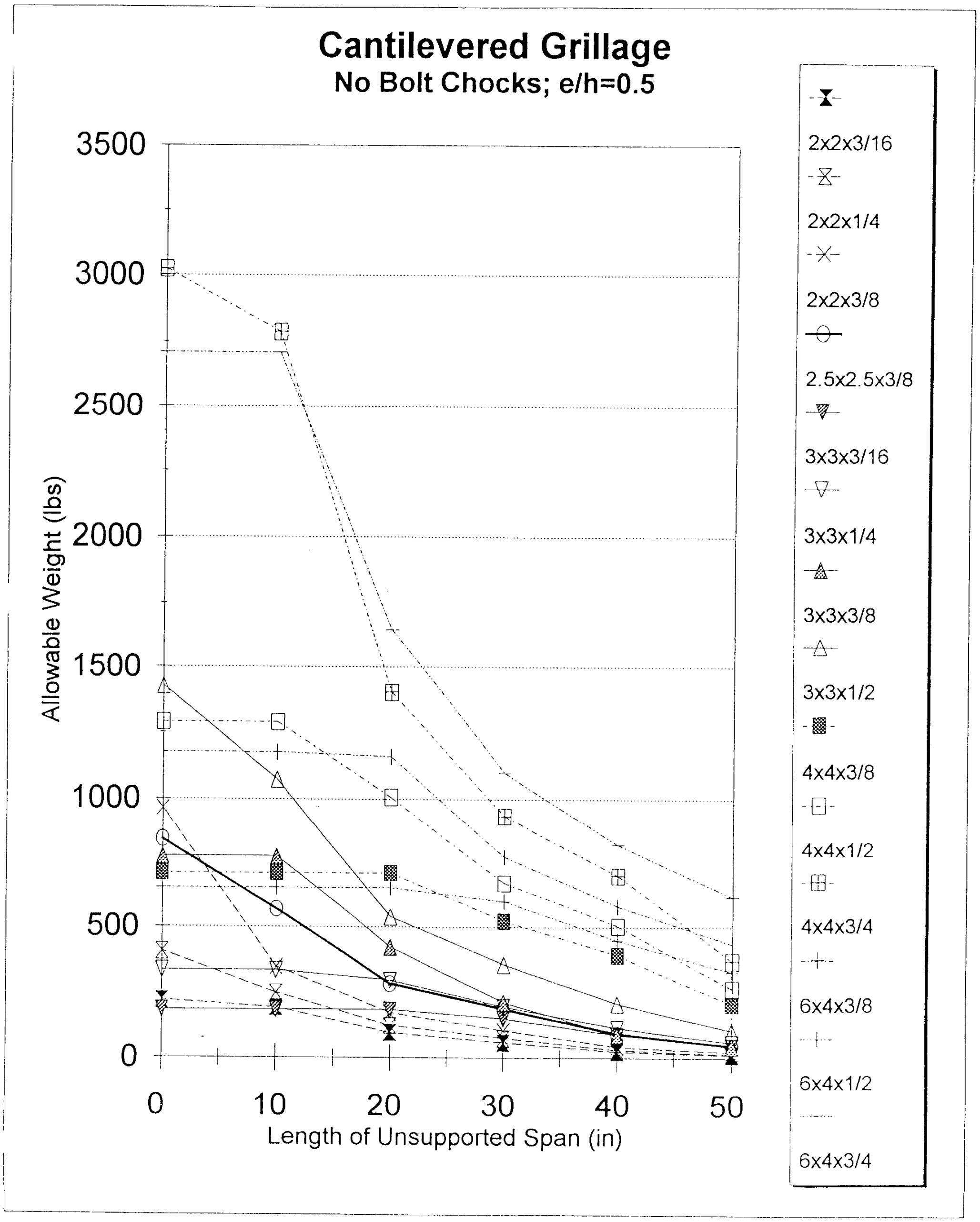
	2×2×3/16			2×2×¼			2×2×3/8			2.5×2.5×3/8		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	816	816	614	1088	1088	818	1632	1632	1227	1632	1632	1227
10	770	454	322	989	585	415	1378	822	586	1632	1330	947
20	390	229	162	500	295	209	697	414	294	1135	671	476
30	261	153	108	335	197	139	467	277	197	760	449	318
40	196	115	81	252	148	105	351	208	146	572	337	239
50	157	85	43	202	109	54	281	150	75	458	270	154

	3×3×3/16			3×3×¼			3×3×3/8			3×3×½		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	816	816	614	1088	1088	818	1632	1632	1227	2176	2176	1636
10	816	816	614	1088	1088	818	1632	1632	1227	2176	2176	1636
20	816	531	375	1088	691	489	1632	991	703	2130	1264	899
30	609	355	251	790	463	327	1126	663	470	1429	846	601
40	458	267	188	595	348	246	847	498	294	1075	635	451
50	367	214	150	477	278	195	679	301	150	861	509	347

	4×4×3/8			4×4×½			4×4×¾		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	1632	1632	1227	2176	2176	1636	3264	3264	2454
10	1632	1632	1227	2176	2176	1636	3264	3264	2454
20	1632	1632	1227	2176	2176	1636	3264	3264	2343
30	1632	1216	861	2176	1567	1111	3264	2203	1567
40	1560	914	647	2002	1178	835	2789	1656	1177
50	1251	733	518	1605	944	669	2237	1327	943

	6×4×3/8			6×4×½			6×4×3/4		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	1632	1632	1227	2176	2176	1636	3264	3264	2454
10	1632	1632	1227	2176	2176	1636	3264	3264	2454
20	1632	1632	1227	2176	2176	1636	3264	3264	2454
30	1632	1344	838	2176	1741	1216	3264	2476	1730
40	1632	1010	704	2176	1309	913	3264	1861	1300
50	1432	809	564	1853	1048	731	2626	1491	1041

CANTILEVERED GRILLAGE RESULTS


Cantilevered Grillage
No Bolt Chocks; e/h=0.5
3500
3000
2500
2000
1500
1000
500
0
Allowable Weight (lbs)
0
10
20
30
40
50
Length of Unsupported Span (in)
2x2x3/16
2x2x1/4
2x2x3/8
2.5x2.5x3/8
3x3x3/16
3x3x1/4
3x3x3/8
3x3x1/2
4x4x3/8
4x4x1/2
4x4x3/4
6x4x3/8
6x4x1/2
6x4x3/4

Figure

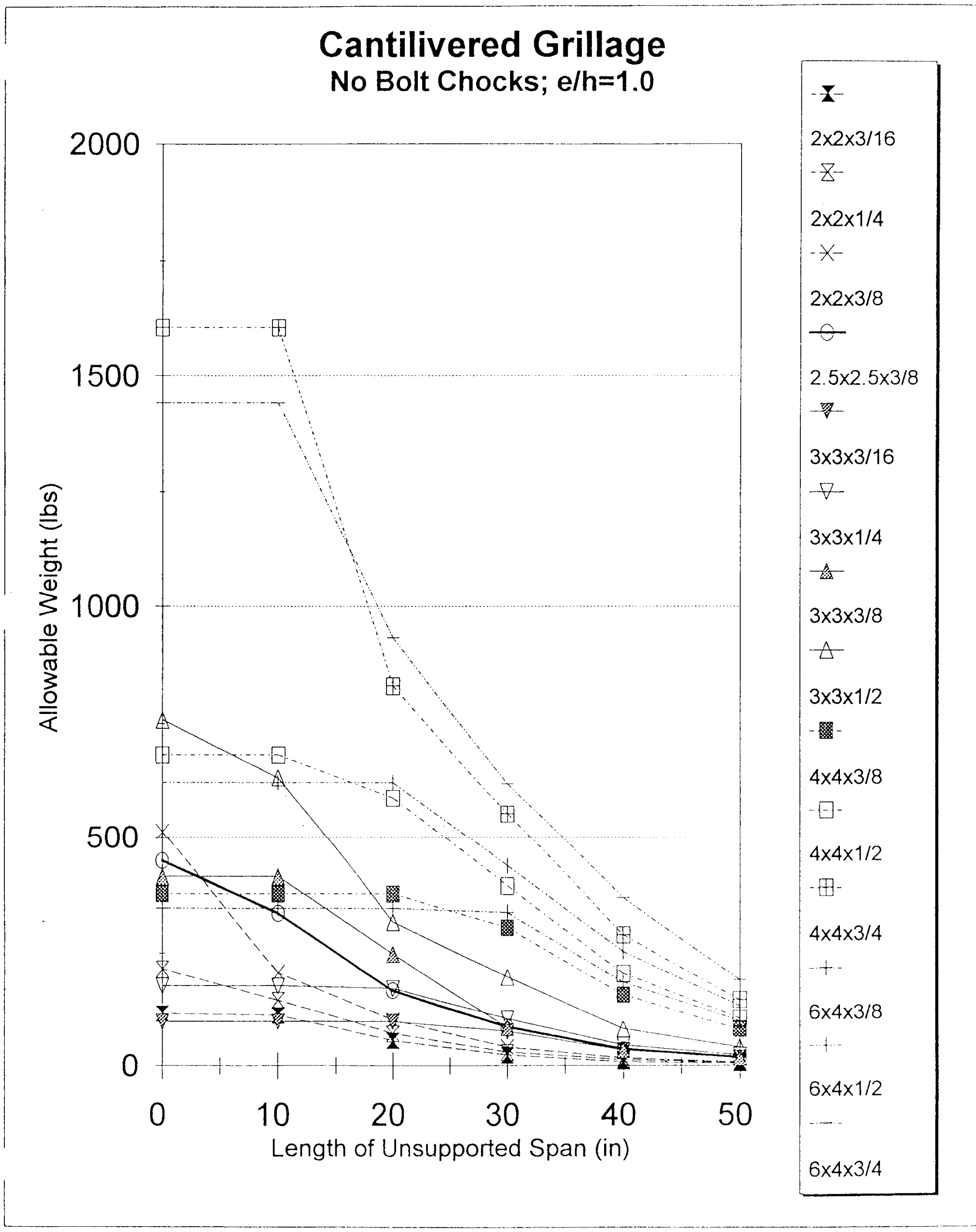


Figure 7-11 — Cantelevered Grillage, No Bolt Chocks;   e/h = 1.0

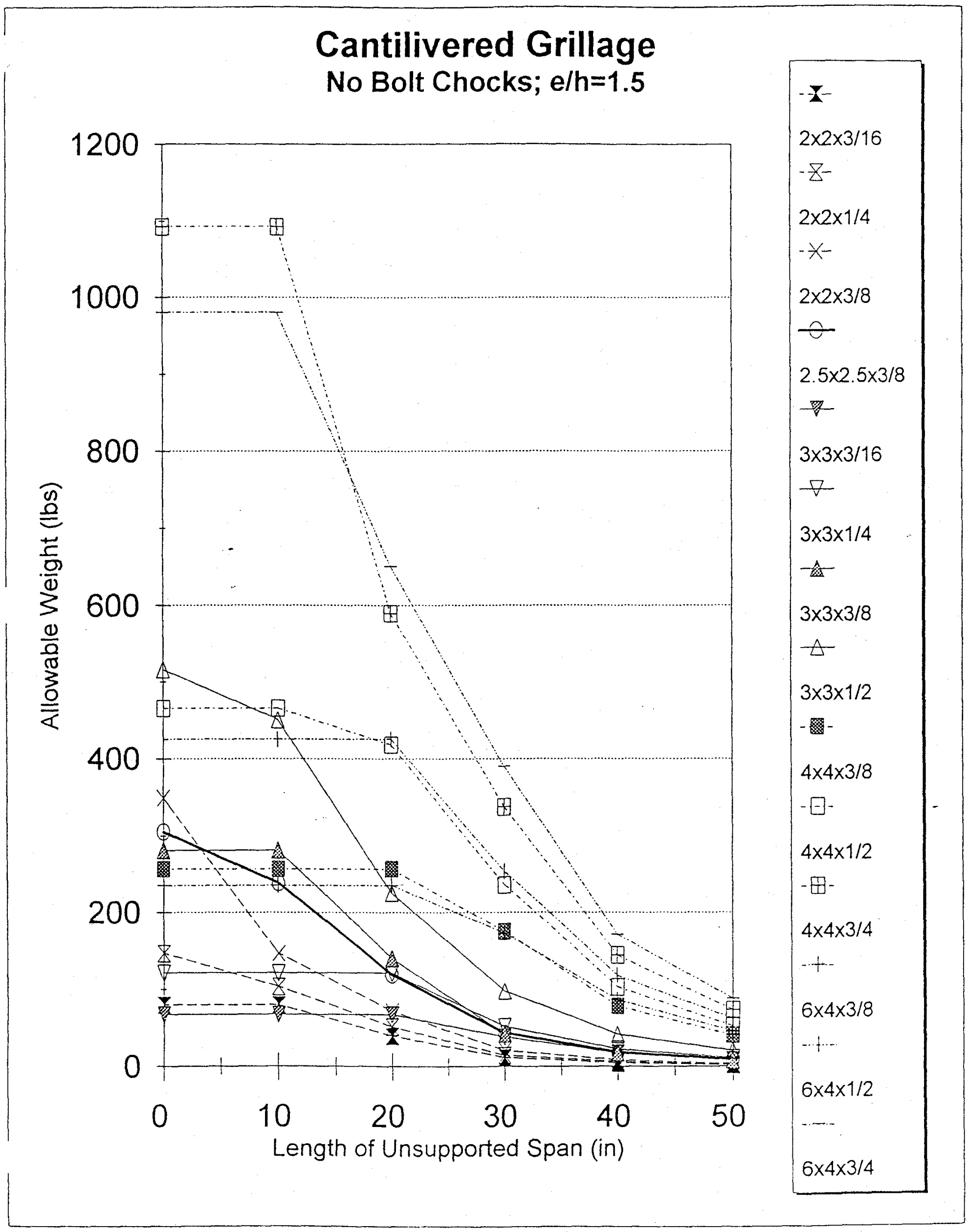


Figure 7-12 — Cantelevered Grillage, No Bolt Chocks; e/h = 1.5

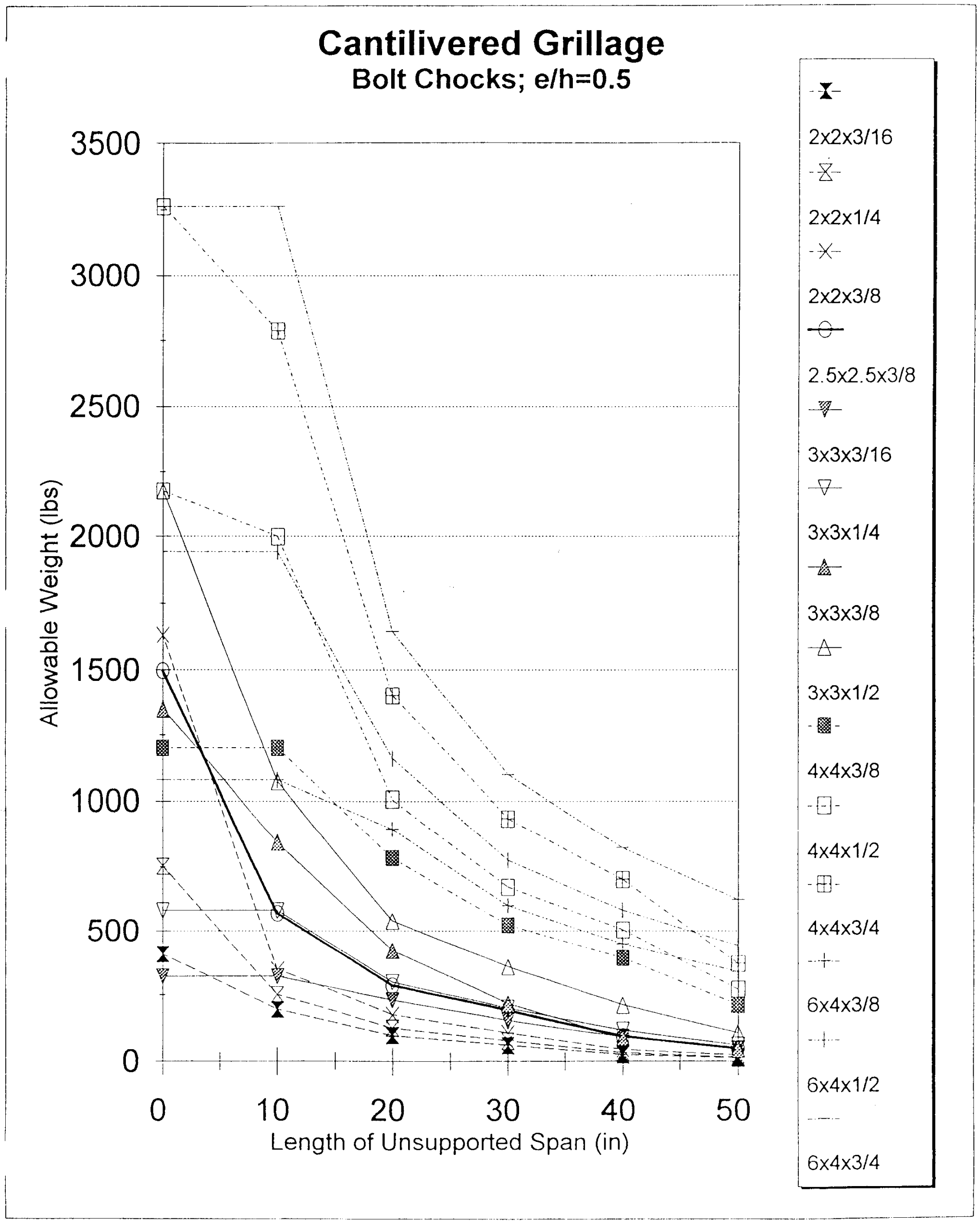


Figure 7-13 — Cantelevered Grillage, Bolt Chocks; e/h = 0.5

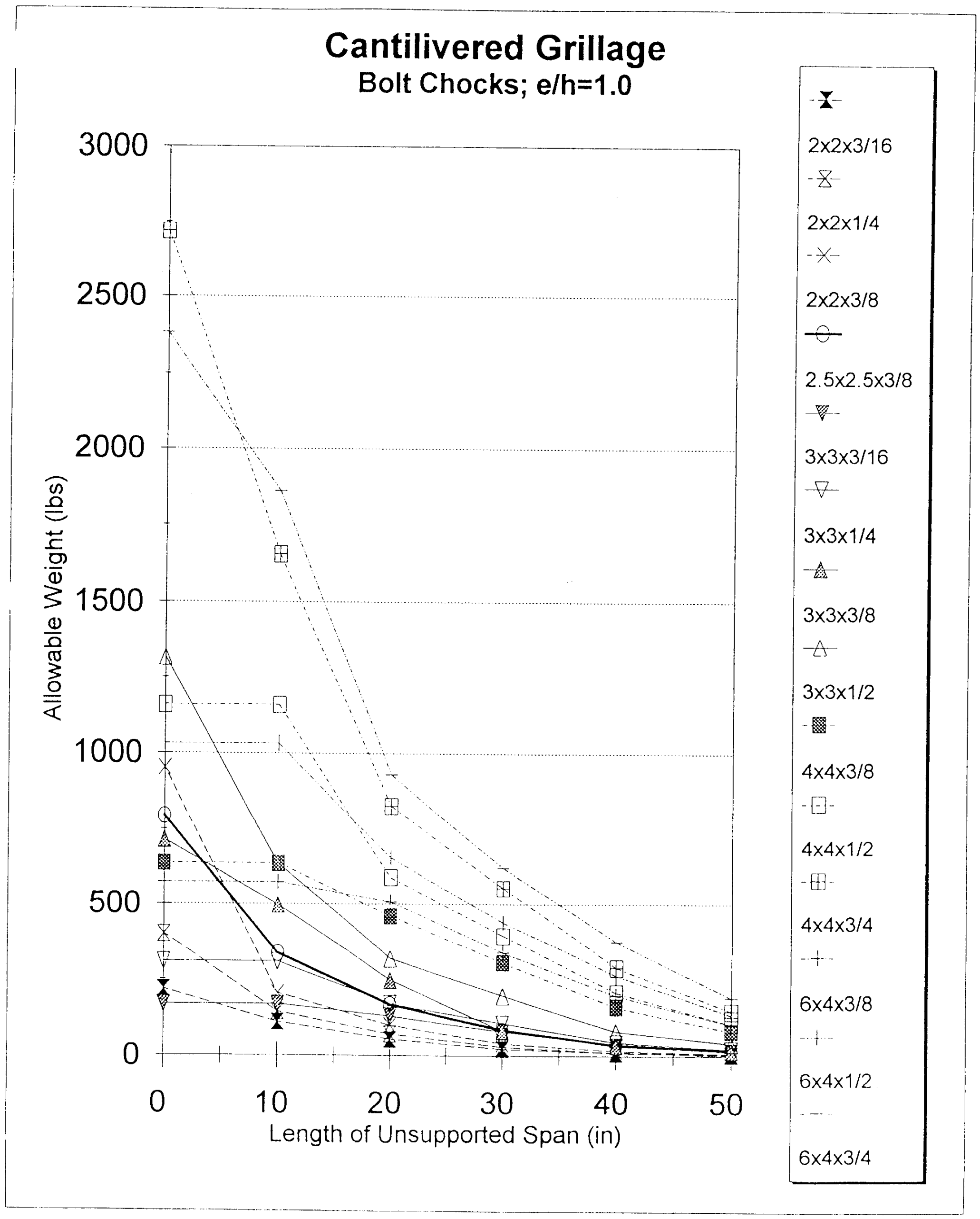


Figure 7-14 — Cantelevered Grillage, Bolt Chocks; e/h = 1.0

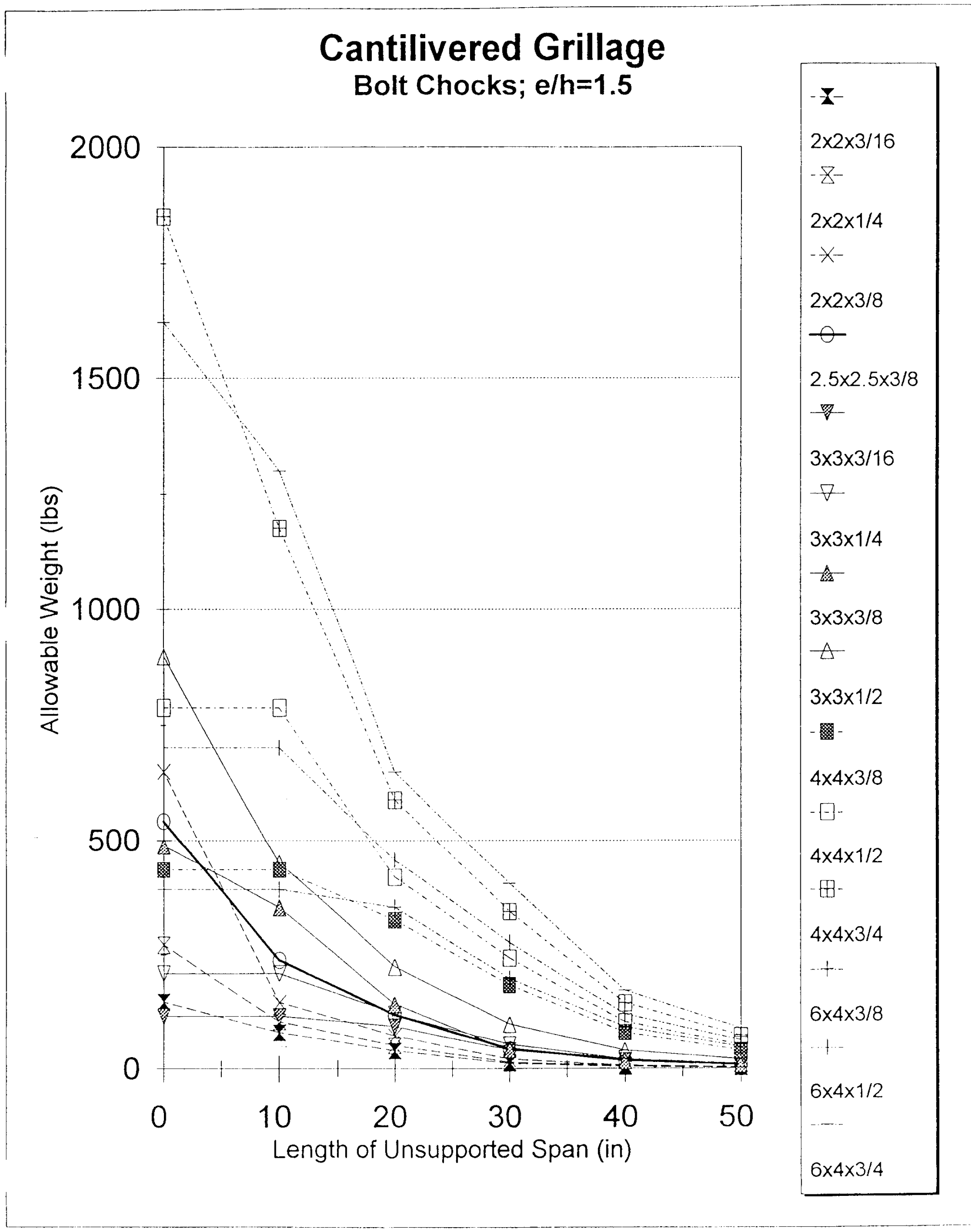


Figure 7-15 — Cantelevered Grillage, Bolt Chocks; e/h = 1.5

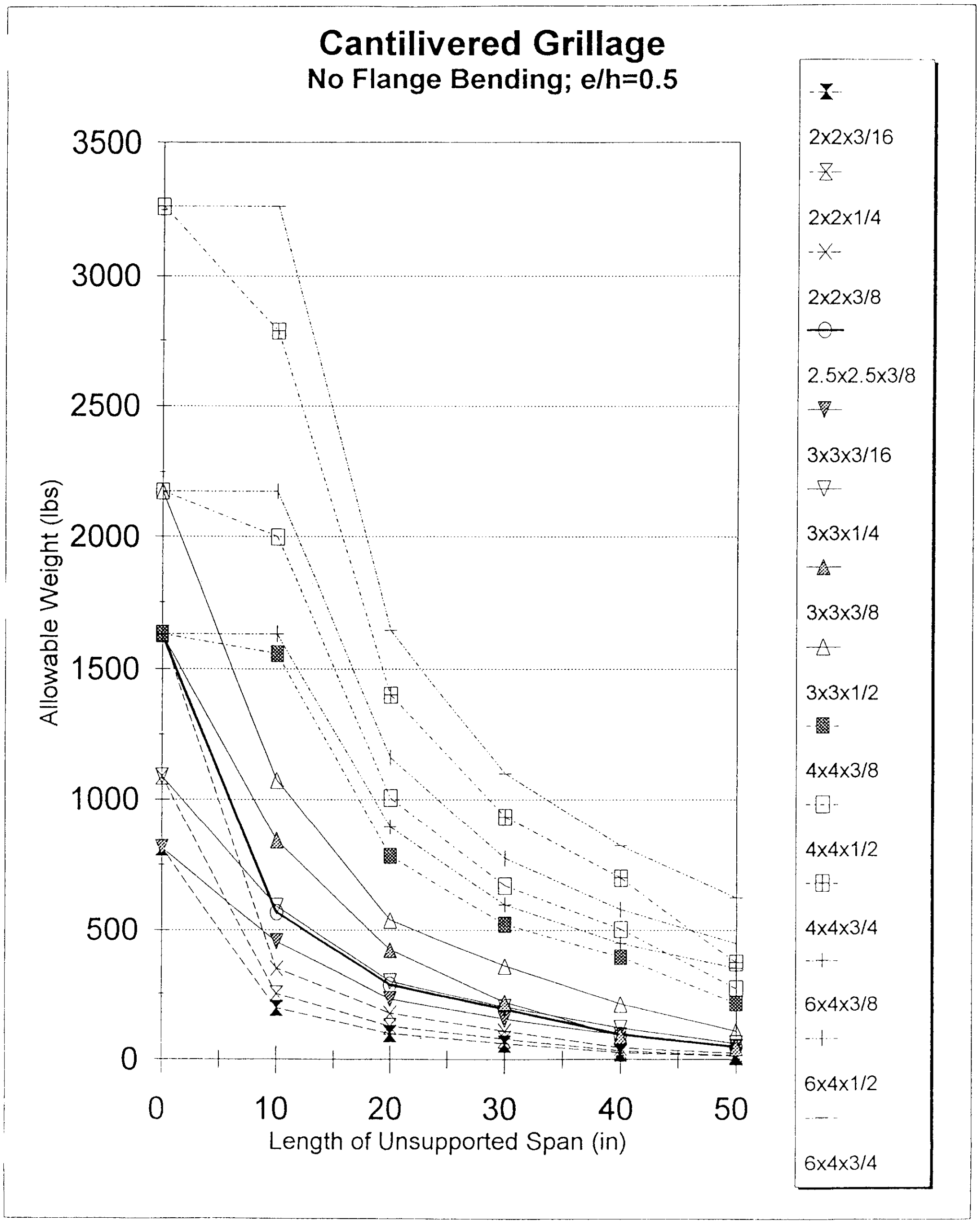


Figure 7-16 — Cantelevered Grillage, No Flange Bending;   e/h = 0.5

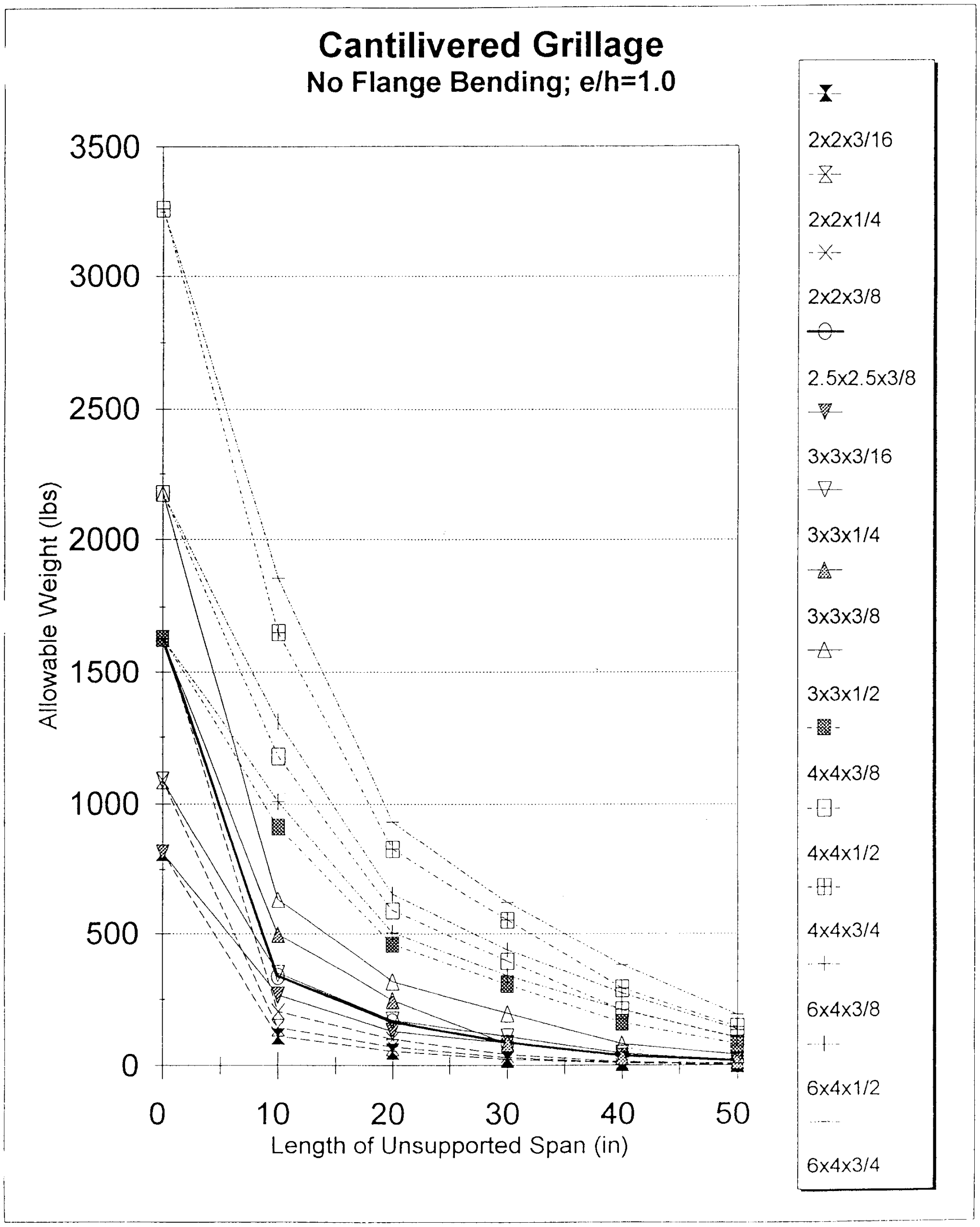


Figure 7-17 — Cantelevered Grillage, No Flange Bending;   e/h = 1.0

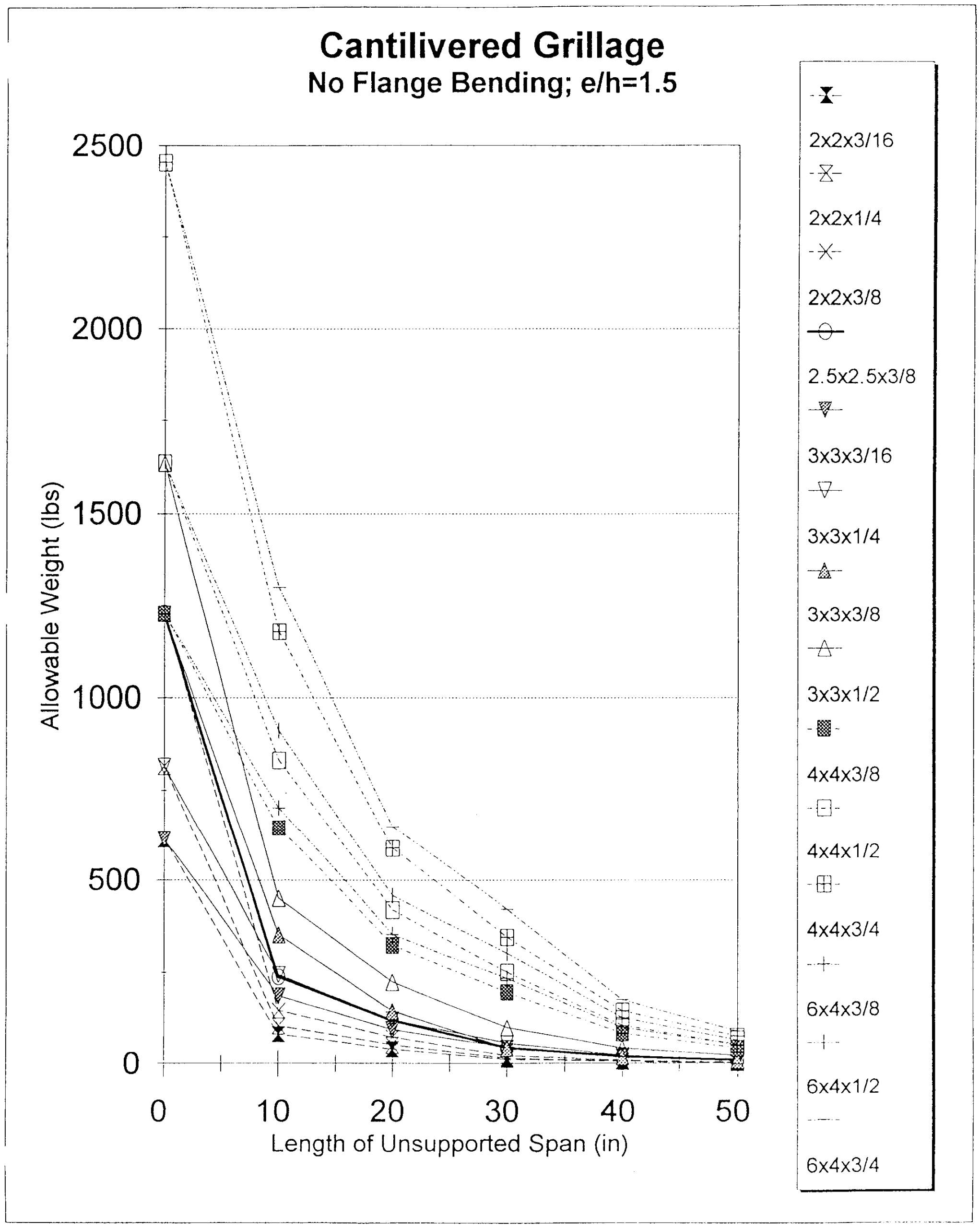


Figure 7-18 — Cantilevered Grillage, No Flange Bending; e/h = 1.5

ALLOWABLE GRILLAGE WEIGHTS — CANTILEVERED GRILLAGE — NO BOLT CHOCKS (ALLOWABLE WEIGHT IN LBS.)

	2×2×3/16			2×2×¼			2×2×3/8			2.5×2.5×3/8		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	224	119	81	408	217	147	966	513	350	845	449	306
10	196	115	81	252	148	105	351	208	148	572	337	239
20	98	57	40	126	74	52	176	104	73	287	169	120
30	61	24	12	78	31	16	108	43	22	192	88	44
40	26	10	5	33	13	7	46	18	9	94	37	19
50	13	5	3	17	7	3	23	9	5	48	19	10

	3×3×3/16			3×3×¼			3×3×3/8			3×3×½		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	187	99	68	337	179	122	780	414	282	1428	758	516
10	187	99	68	337	179	122	780	414	282	1075	635	451
20	187	99	68	299	174	122	425	250	140	540	319	226
30	154	79	39	199	107	53	216	86	43	360	198	99
40	89	35	18	117	46	23	92	37	18	211	84	42
50	46	18	9	60	24	12	47	19	9	108	43	22

	4×4×3/8			4×4×½			4×4×3/8		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	711	378	257	1290	685	466	3024	1606	1094
10	711	378	257	1290	685	466	3024	1606	1094
20	711	378	257	1007	591	418	1403	831	590
30	524	306	176	673	395	237	937	555	339
40	394	159	79	505	207	103	703	290	145
50	210	83	42	270	107	54	374	149	75

	6×4×3/8			6×4×½			6×4×3/8		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	654	347	236	1176	625	425	2713	1441	981
10	654	347	236	1176	625	425	2713	1441	981
20	654	347	236	1162	625	425	1647	933	651
30	600	338	173	776	438	254	1100	623	390
40	450	187	87	583	255	118	826	369	172
50	331	102	47	437	135	63	619	192	89

ALLOWABLE GRILLAGE WEIGHTS — CANTILEVERED GRILLAGE — BOLT CHOCKS (ALLOWABLE WEIGHT IN LBS.)

L	2×2×3/16			2×2×¼			2×2×3/8			2.5×2.5×3/8		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	411	219	149	753	400	272	1632	956	651	1500	797	543
10	196	115	81	252	148	105	351	208	148	572	337	239
20	98	57	41	126	74	52	176	104	73	287	169	120
30	61	25	12	79	31	16	108	43	22	192	89	44
40	26	10	5	33	13	7	46	18	9	94	38	19
50	13	5	3	17	7	3	23	9	5	48	19	10

L	3×3×3/16			3×3×¼			3×3×3/8			3×3×½		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	322	171	117	582	309	210	1350	717	488	2176	1316	896
10	322	171	117	582	309	210	847	498	353	1075	635	451
20	230	134	94	299	174	123	425	250	144	540	319	226
30	154	83	41	199	110	55	217	87	43	360	200	100
40	91	36	18	118	47	23	92	37	18	211	84	42
50	47	19	9	61	24	12	47	19	9	108	43	22

L	4×4×3/8			4×4×½			4×4×¾		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	1200	638	434	2176	1157	788	3264	2720	1852
10	1200	638	434	2176	1157	788	3264	2720	1852
20	785	459	324	1007	591	418	1403	831	590
30	524	306	186	673	395	244	937	555	343
40	394	163	81	505	210	105	703	291	146
50	212	84	42	271	108	54	374	150	75

L	6×4×3/8			6×4×½			6×4×3/4		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	1080	574	391	1944	1033	703	3264	2384	1623
10	1080	574	391	1944	1033	703	3264	2384	1623
20	898	507	353	1162	656	457	1647	933	651
30	600	338	200	776	438	276	1100	623	405
40	450	200	93	583	264	123	826	375	174
50	341	106	49	444	138	64	623	193	50

ALLOWABLE GRILLAGE WEIGHTS — GRILLAGE WITH SIMPLY SUPPORTED SPANS — NO FLANGE BENDING (ALLOWABLE WEIGHT IN LBS.)

	2×2×3/16			2×2×¼			2×2×3/8			2.5×2.5×3/8		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	816	816	614	1088	1088	818	1632	1632	1227	1632	1632	1227
10	196	115	81	252	148	105	351	208	148	572	337	239
20	98	57	41	126	74	52	176	104	73	287	169	120
30	62	25	12	79	31	16	108	43	22	192	89	45
40	26	10	5	33	13	7	46	18	9	94	38	19
50	13	5	3	17	7	3	23	9	5	48	19	10

	3×3×3/16			3×3×¼			3×3×3/8			3×3×½		
L	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	816	816	614	1088	1088	818	1632	1632	1227	2176	2176	1636
10	458	268	188	595	348	246	847	498	353	1075	635	451
20	230	134	94	299	174	123	425	250	147	540	319	226
30	154	87	44	199	113	56	218	87	44	360	201	100
40	92	37	18	119	48	24	92	37	18	212	85	42
50	47	19	9	61	24	12	47	19	9	108	43	22

L	4×4×3/8			4×4×½			4×4×¾		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	1632	1632	1227	2176	2176	1636	3264	3264	2454
10	1560	914	647	2002	1178	835	2789	1656	1177
20	785	459	324	1007	591	418	1403	831	590
30	524	306	197	673	395	252	937	555	347
40	394	166	83	505	212	106	703	293	146
50	213	85	43	272	109	54	375	150	75

L	6×4×3/8			6×4×½			6×4×3/4		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	1632	1632	1227	2176	2176	1636	3264	3264	2454
10	1632	1010	704	2176	1309	913	3264	1861	1300
20	898	507	353	1162	656	457	1647	933	651
30	600	338	235	776	538	303	1100	623	420
40	450	215	100	583	275	128	826	381	177
50	352	110	51	451	141	65	627	195	91

SOFT PLATE RESULTS

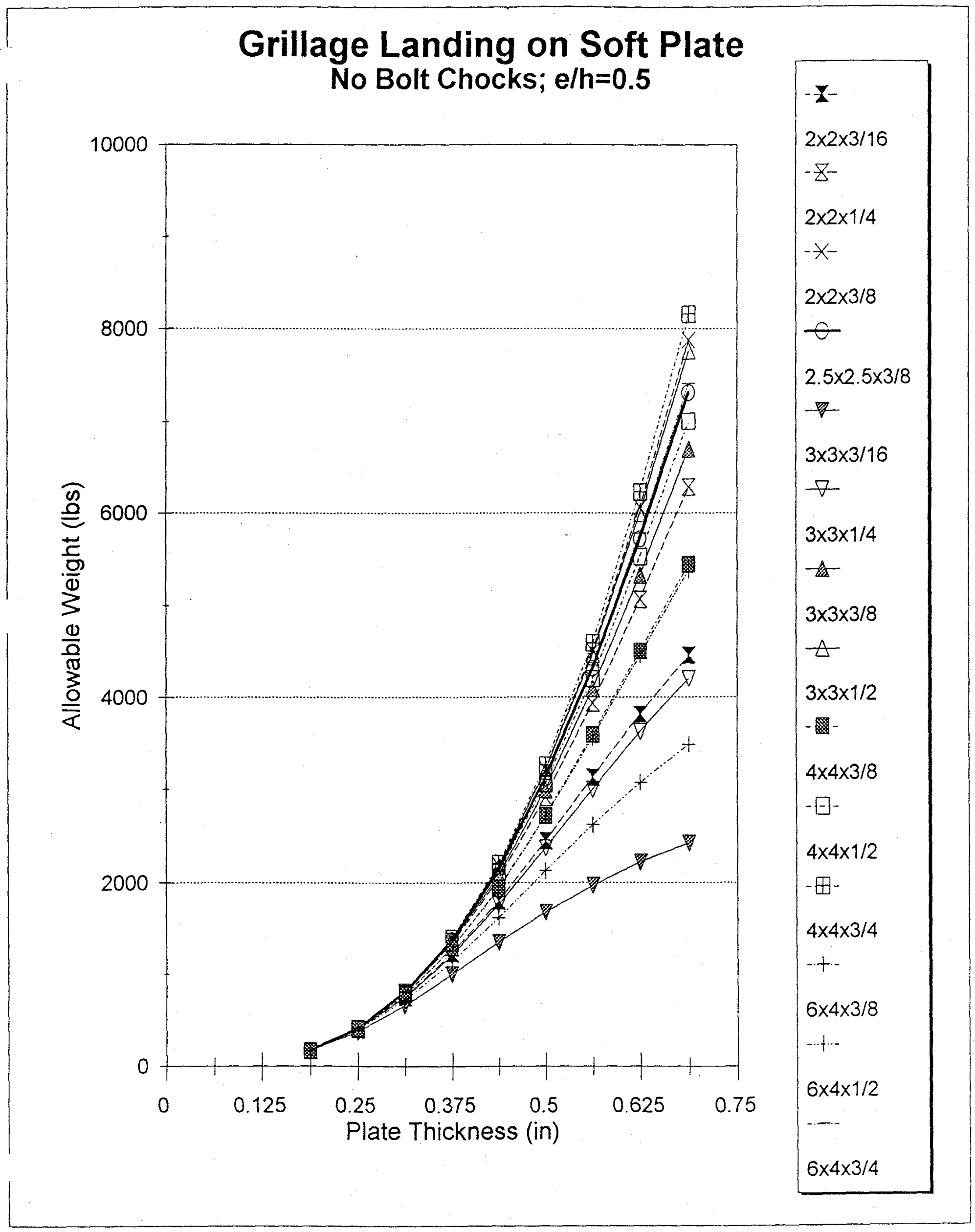


Figure 7-19 — Grillage Landing on Soft Plate, No Bolt Chocks; e/h = 0.5

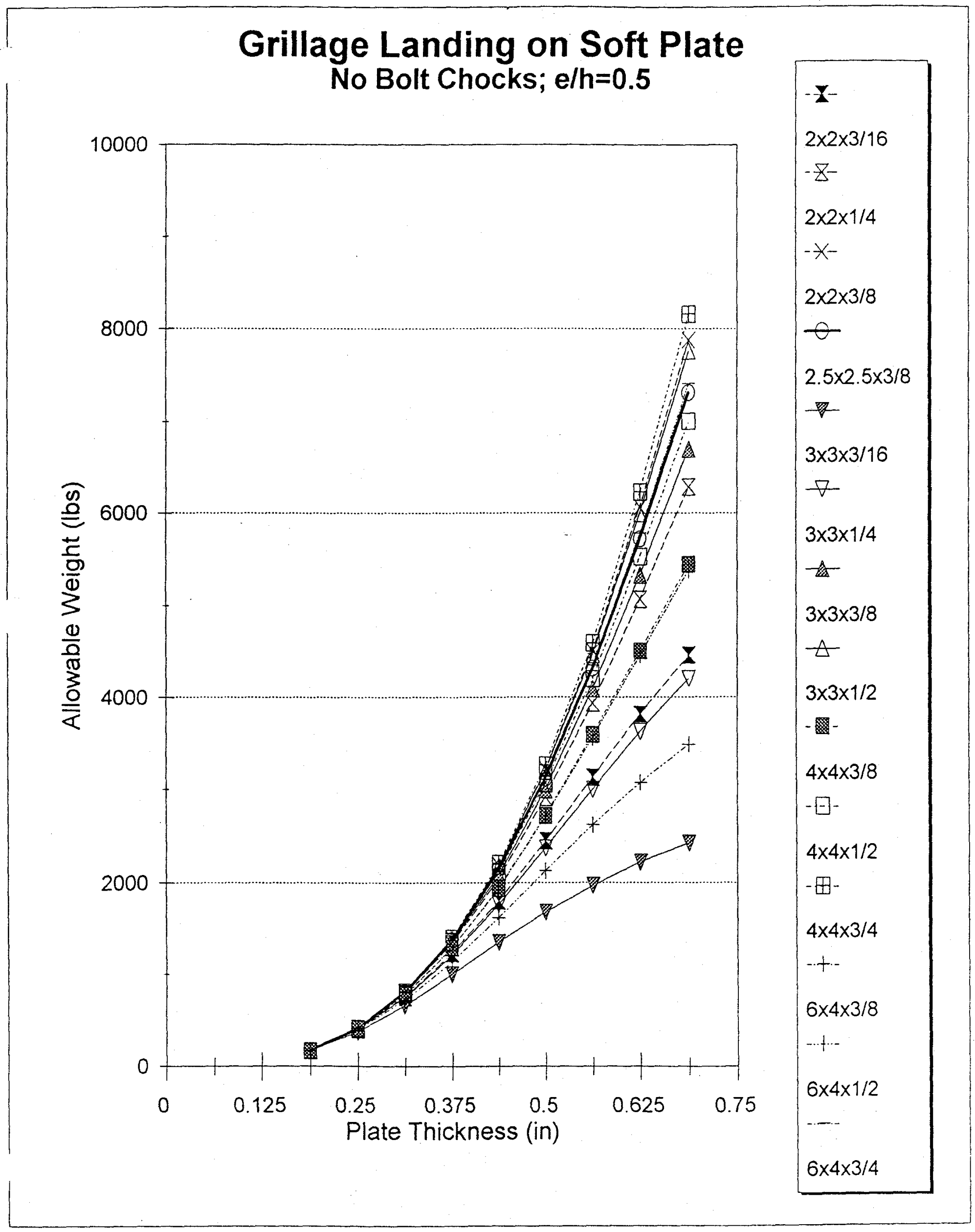


Figure 7-19 — Grillage Landing on Soft Plate, No Bolt Chocks; e/h = 0.5

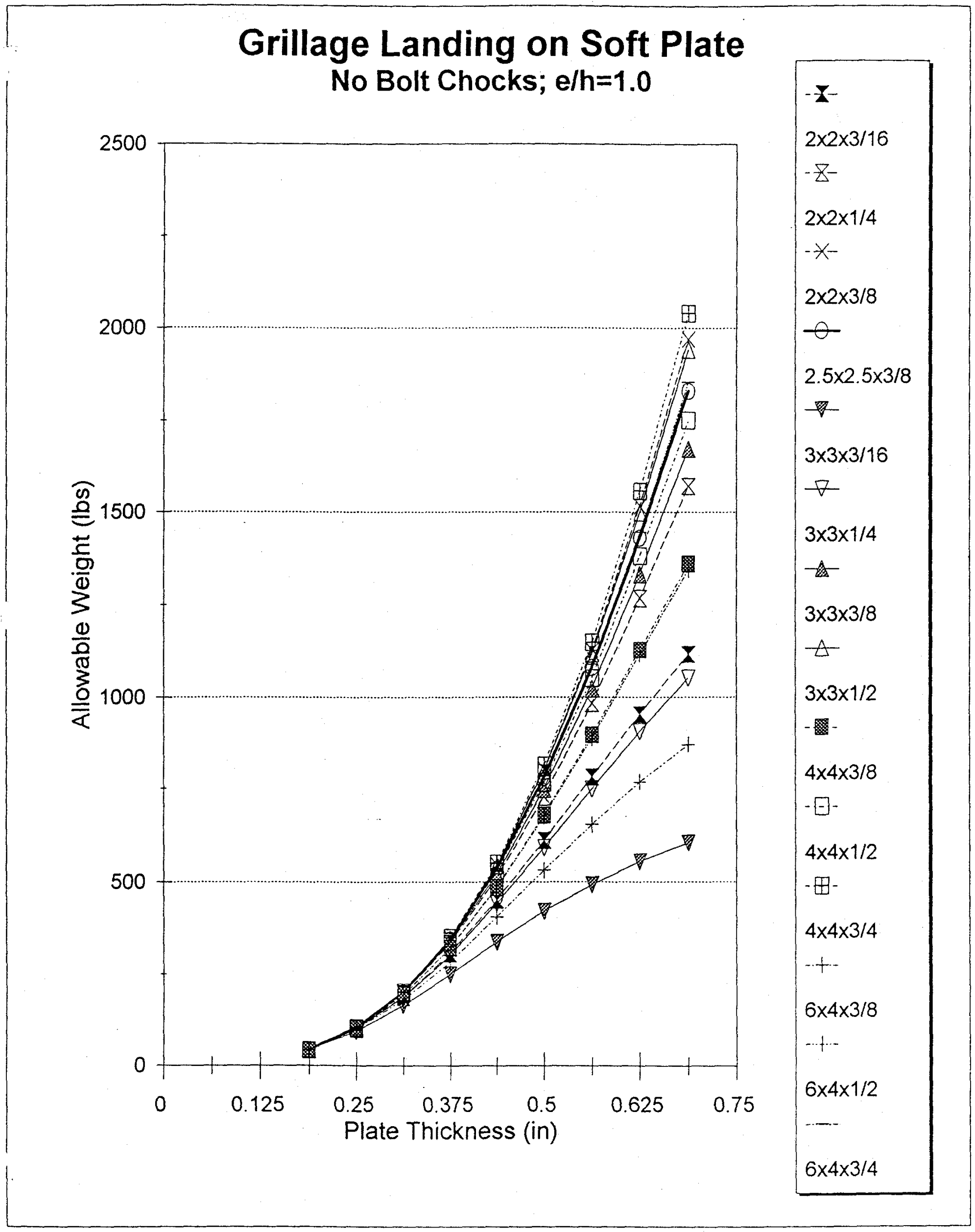


Figure 7-20 — Grillage Landing on Soft Plate, No Bolt Chocks; e/h = 1.0

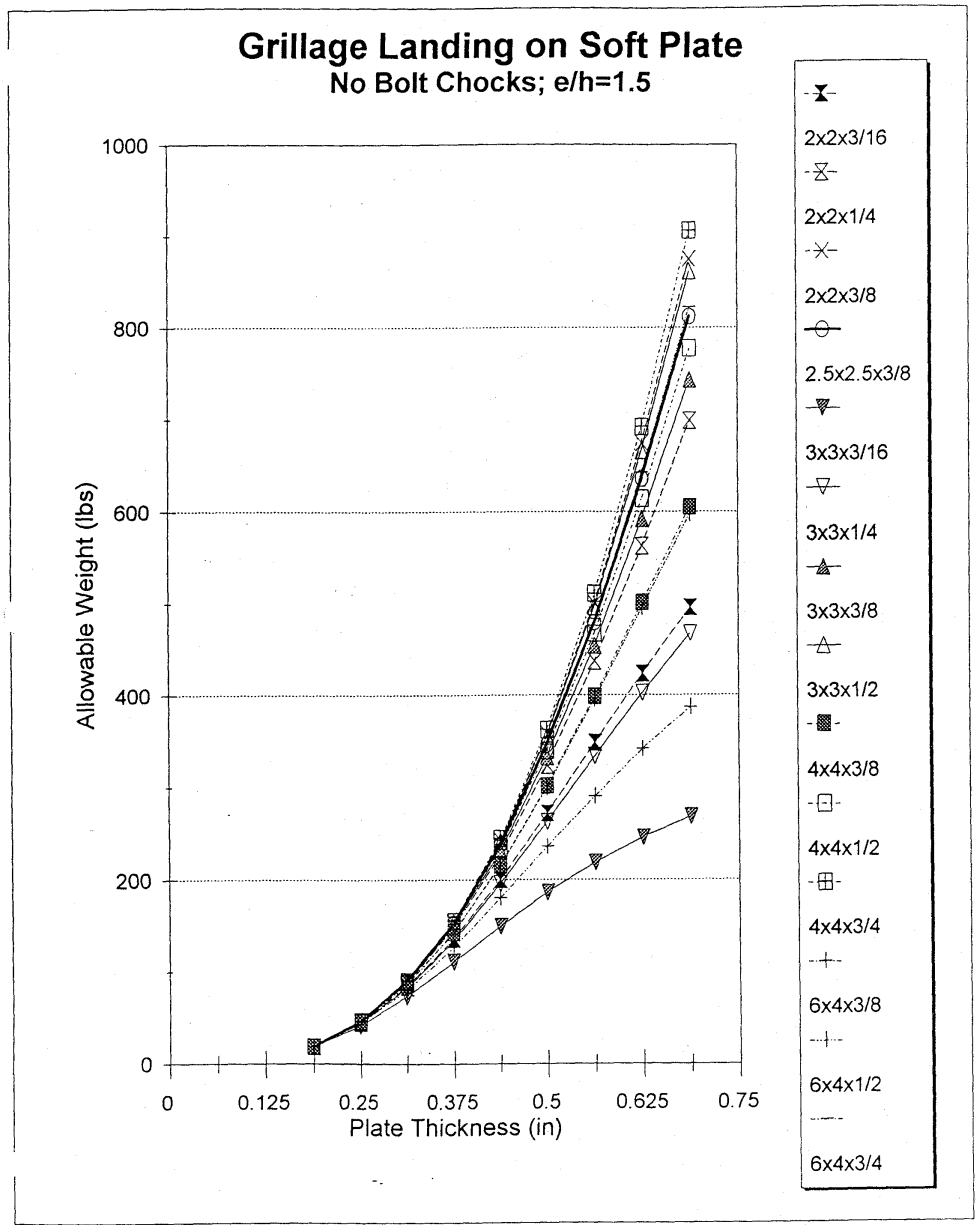


Figure 7-21 — Grillage Landing on Soft Plate, No Bolt Chocks; e/h = 1.5

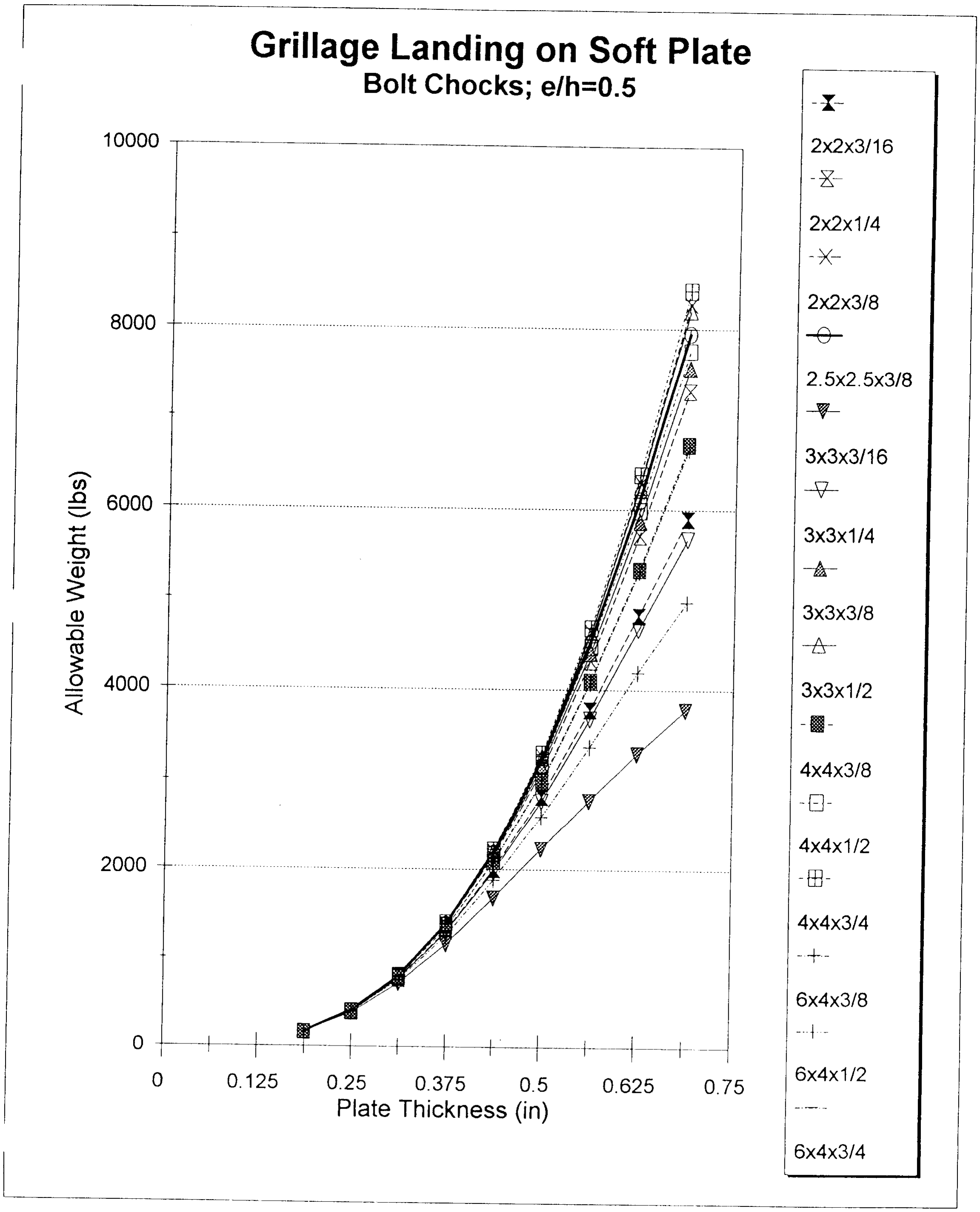


Figure 7-22 — Grillage Landing on Soft Plate, Bolt Chocks; e/h = 0.5

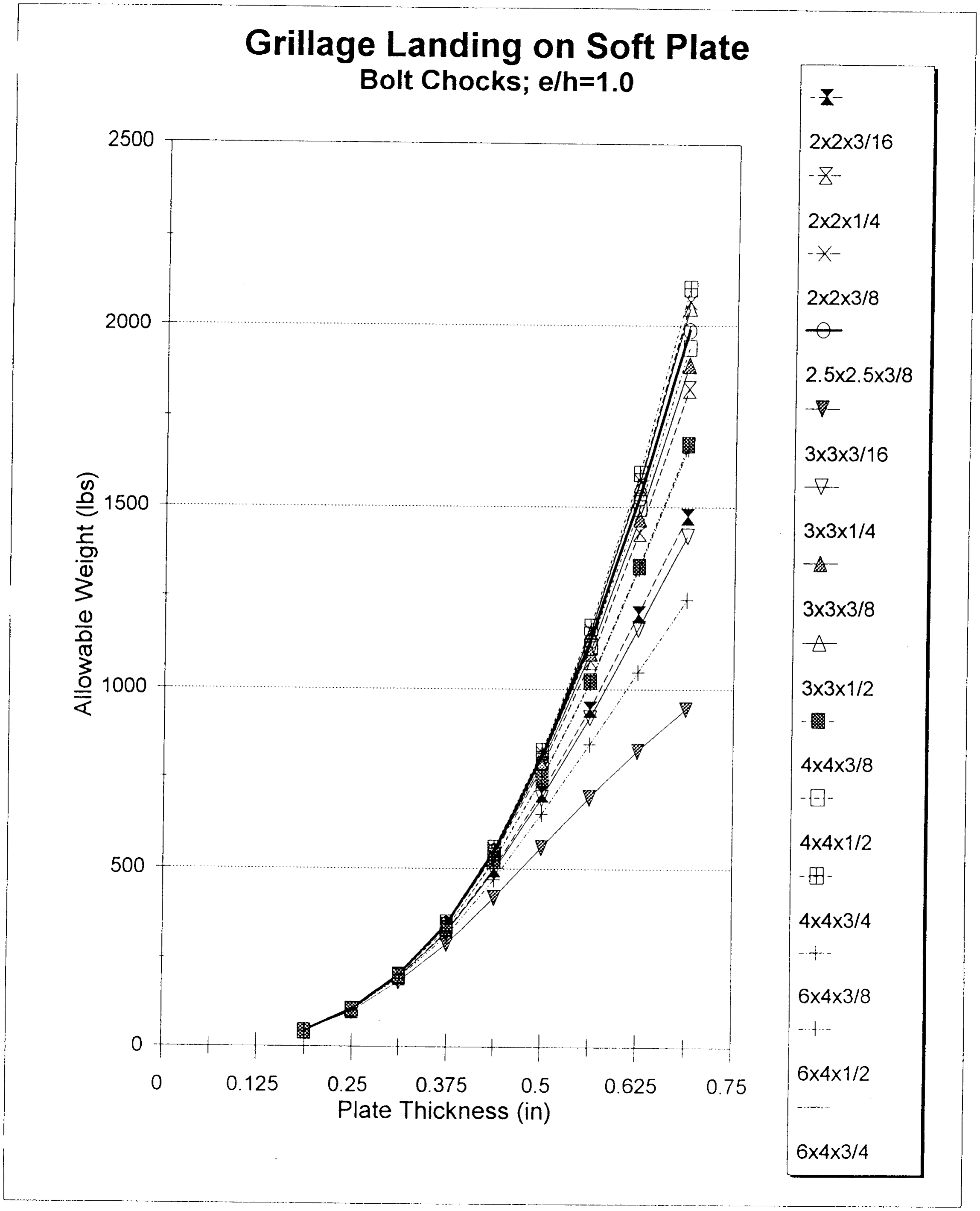


Figure 7-23 — Grillage Landing on Soft Plate, Bolt Chocks; e/h = 1.0

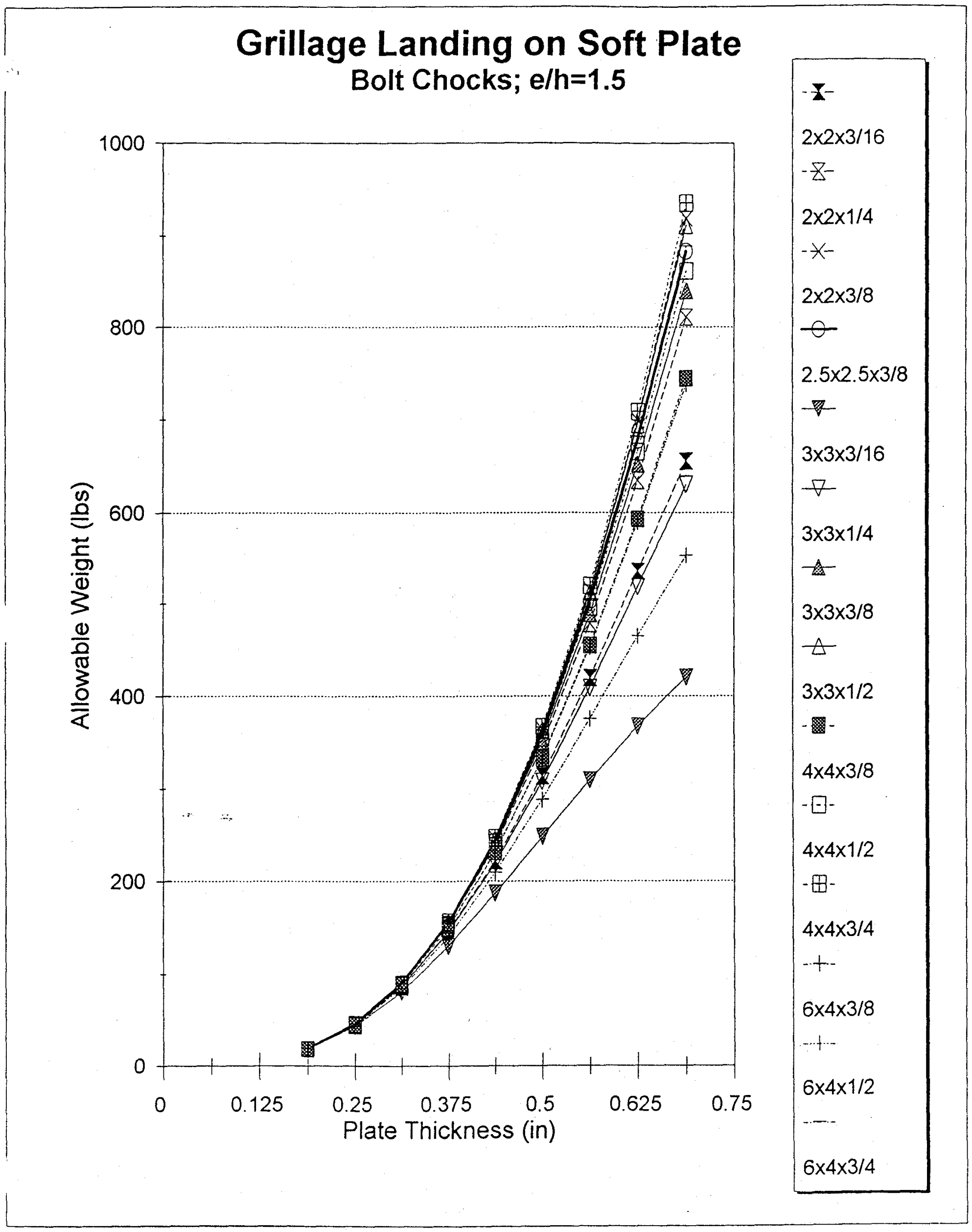


Figure 7-24 — Grillage Landing on Soft Plate, Bolt Chocks; e/h = 1.5

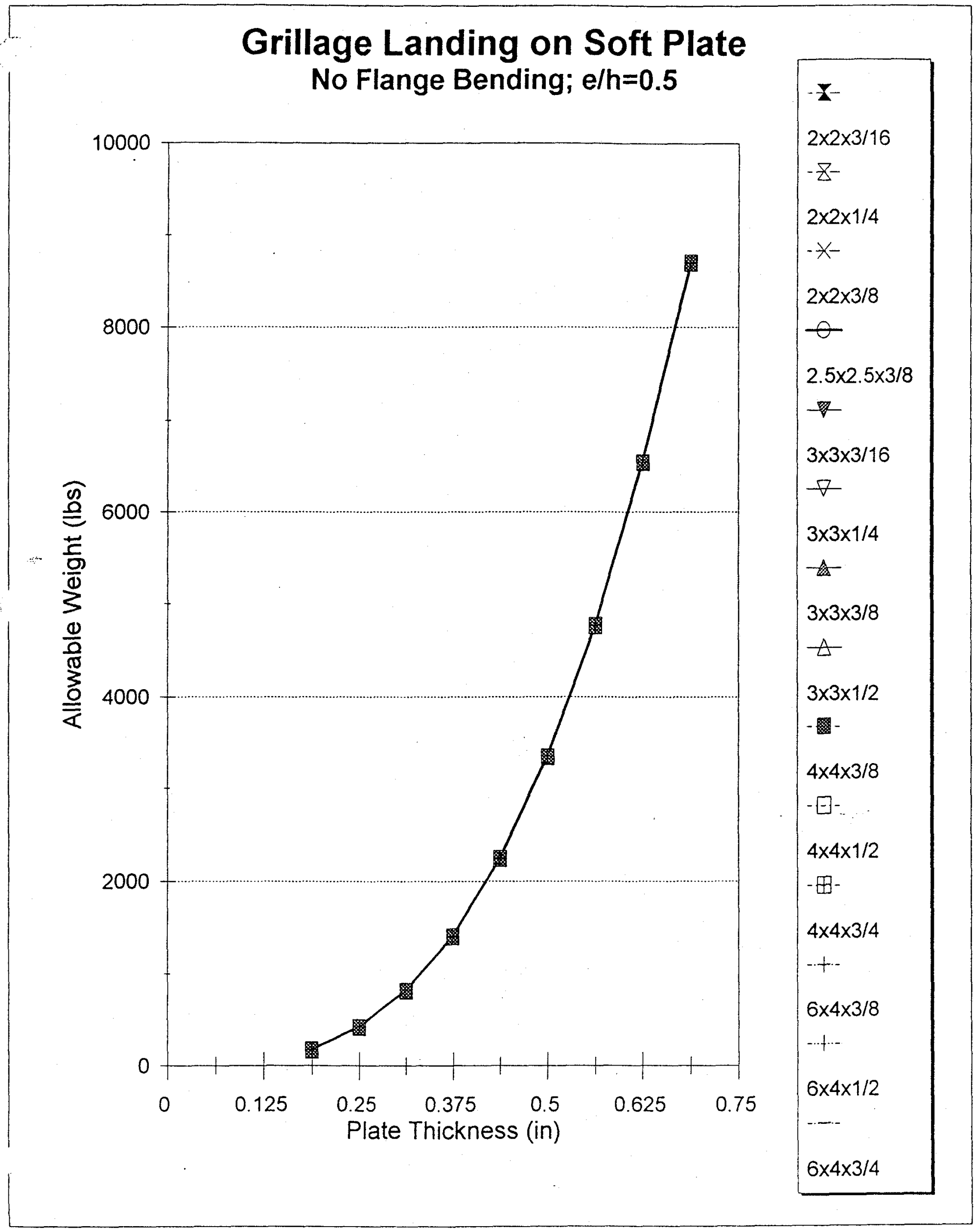


Figure 7-25 — Grillage Landing on Soft Plate, No Flange Bending; e/h = 0.5

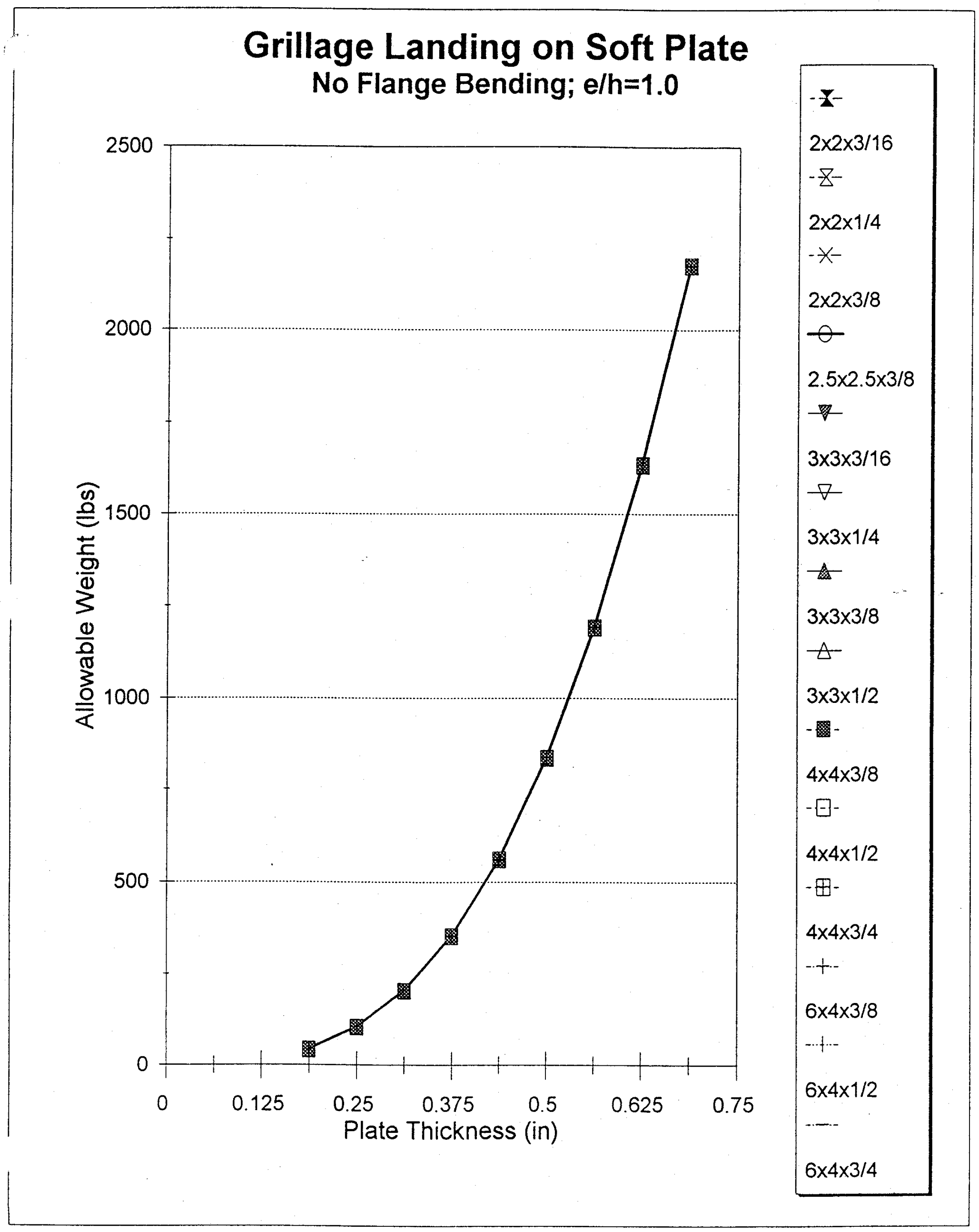


Figure 7-26 — Grillage Landing on Soft Plate, No Flange Bending; e/h = 1.0

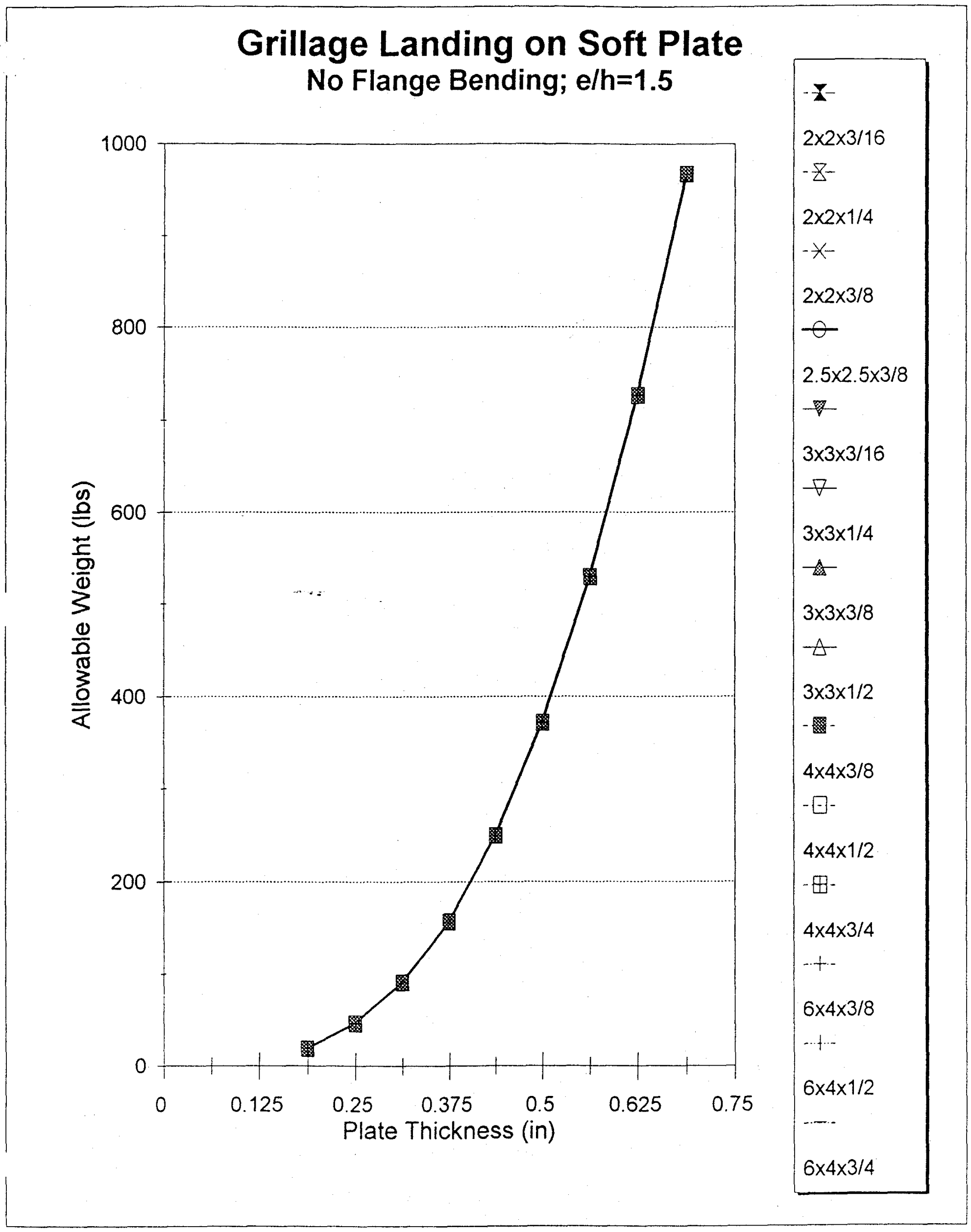


Figure 7-27 — Grillage Landing on Soft Plate, No Flange Bending; e/h = 1.5

Table 7-1 — Allowable Grillage Weights For Soft Plate — Grillage With Simply Supported Spans— No Bolt Chocks

(ALLOWABLE WEIGHT IN LBS.)

PLATE T	2×2×3/16			2×2×¼			2×2×3/8			2.5×2.5×3/8		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	173	43	19	175	44	19	176	44	20	176	44	20
0.2500	400	100	44	411	103	46	417	104	46	415	104	46
0.3125	751	188	83	789	197	88	810	202	90	804	201	89
0.3750	1225	306	136	1330	333	148	1390	347	154	1371	343	152
0.4375	1803	451	200	2042	510	227	2185	546	243	2140	535	238
0.5000	2453	613	273	2918	730	324	3221	805	358	3122	780	347
0.5625	3137	784	349	3940	985	438	4511	1128	501	4320	1080	480
0.6250	3817	954	424	5076	1269	564	6066	1517	674	5725	1431	636
0.6875	4465	1116	496	6289	1572	699	7884	1971	876	7317	1829	813

PLATE T	3×3×3/16			3×3×¼			3×3×3/8			2.5×2.5×3/8		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	168	42	19	173	43	19	176	44	20	176	44	20
0.2500	372	93	41	398	100	44	413	103	46	416	104	46
0.3125	658	164	73	743	186	83	795	199	88	809	202	90
0.3750	994	249	110	1204	301	134	1348	337	150	1386	347	154
0.4375	1344	336	149	1760	440	196	2083	521	231	2177	544	242
0.5000	1676	419	186	2374	594	264	3003	751	334	3202	800	356
0.5625	1969	492	219	3009	752	334	4095	1024	455	4475	1119	497
0.6250	2217	554	246	3629	907	403	5336	1334	593	6000	1500	667
0.6875	2421	605	269	4210	1052	468	6694	1673	744	7772	1943	864

PLATE T	4×4×3/8			4×4×½			4×4×¾		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	175	44	19	176	44	20	176	44	20
0.2500	407	102	45	414	103	46	417	104	46
0.3125	774	194	86	800	200	89	813	203	90
0.3750	1288	322	143	1360	340	151	1398	350	155
0.4375	1944	486	216	2112	528	235	2206	552	245
0.5000	2723	681	303	3063	766	340	3266	817	363
0.5625	3592	898	399	4209	1052	468	4602	1150	511
0.6250	4513	1128	501	5531	1383	615	6230	1558	692
0.6875	5447	1362	605	7004	1751	778	8163	2041	907

PLATE T	6×6×3/8			6×4×½			6×4×¾		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	171	43	19	174	44	19	176	44	20
0.2500	391	98	43	407	102	45	415	104	46
0.3125	717	179	80	773	193	86	805	201	89
0.3750	1137	284	126	1285	321	143	1374	344	153
0.4375	1619	405	180	1936	484	215	2148	537	239
0.5000	2125	531	236	2707	677	301	3139	785	349
0.5625	2620	655	291	3564	891	396	4354	1088	484
0.6250	3078	770	342	4469	1117	497	5785	1446	643
0.6875	3486	872	387	5384	1346	598	7415	1854	824

Table 7-2 — Allowable Grillage Weights — Grillage With Simply Supported Spans — No Flange Bending

(ALLOWABLE WEIGHT IN LBS.)

L	2×2×3/16			2×2×¼			2×2×3/8			2.5×2.5×3/8		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	816	816	614	1088	1088	818	1632	1632	1227	1632	1632	1227
10	196	115	81	252	148	105	351	208	148	572	337	239
20	98	57	41	126	74	52	176	104	73	287	169	120
30	62	25	12	79	31	16	108	43	22	192	89	45
40	26	10	5	33	13	7	46	18	9	94	38	19
50	13	5	3	17	7	3	23	9	5	48	19	10

L	3×3×3/16			3×3×¼			3×3×3/8			3×3×½		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	816	816	614	1088	1088	818	1632	1632	1227	2176	2176	1636
10	458	268	188	595	348	246	847	498	353	1075	635	451
20	230	134	94	299	174	123	425	250	147	540	319	226
30	154	87	44	199	113	56	218	87	44	360	201	100
40	92	37	18	119	48	24	92	37	18	212	85	42
50	47	19	9	61	24	12	47	19	9	108	43	22

L	4×4×3/8			4×4×½			4×4×¾		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	1632	1632	1227	2176	2176	1636	3264	3264	2454
10	1560	914	647	2002	1178	835	2789	1656	1177
20	785	459	324	1007	591	418	1403	831	590
30	524	306	197	673	395	252	937	555	347
40	394	166	83	505	212	106	703	293	146
50	213	85	43	272	109	54	375	150	75

L	6×4×3/8			6×4×½			6×4×3/4		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0	1632	1632	1227	2176	2176	1636	3264	3264	2454
10	1632	1010	704	2176	1309	913	3264	1861	1300
20	898	507	353	1162	656	457	1647	933	651
30	600	338	235	776	538	303	1100	623	420
40	450	215	100	583	275	128	826	381	177
50	352	110	51	451	141	65	627	195	91

Table 7-3 — Allowable Grillage Weights For Soft Plate — Grillage With Simply Supported Spans— No Bolt Chocks

(ALLOWABLE WEIGHT IN LBS.)

PLATE T	2×2×3/16			2×2×¼			2×2×3/8			2.5×2.5×3/8		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	173	43	19	175	44	19	176	44	20	176	44	20
0.2500	400	100	44	411	103	46	417	104	46	415	104	46
0.3125	751	188	83	789	197	88	810	202	90	804	201	89
0.3750	1225	306	136	1330	333	148	1390	347	154	1371	343	152
0.4375	1803	451	200	2042	510	227	2185	546	243	2140	535	238
0.5000	2453	613	273	2918	730	324	3221	805	358	3122	780	347
0.5625	3137	784	349	3940	985	438	4511	1128	501	4320	1080	480
0.6250	3817	954	424	5076	1269	564	6066	1517	674	5725	1431	636
0.6875	4465	1116	496	6289	1572	699	7884	1971	876	7317	1829	813

PLATE T	3×3×3/16			3×3×¼			3×3×3/8			2.5×2.5×3/8		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	168	42	19	173	43	19	176	44	20	176	44	20
0.2500	372	93	41	398	100	44	413	103	46	416	104	46
0.3125	658	164	73	743	186	83	795	199	88	809	202	90
0.3750	994	249	110	1204	301	134	1348	337	150	1386	347	154
0.4375	1344	336	149	1760	440	196	2083	521	231	2177	544	242
0.5000	1676	419	186	2374	594	264	3003	751	334	3202	800	356
0.5625	1969	492	219	3009	752	334	4095	1024	455	4475	1119	497
0.6250	2217	554	246	3629	907	403	5336	1334	593	6000	1500	667
0.6875	2421	605	269	4210	1052	468	6694	1673	744	7772	1943	864

PLATE T	4×4×3/8			4×4×½			4×4×¾		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	175	44	19	176	44	20	176	44	20
0.2500	407	102	45	414	103	46	417	104	46
0.3125	774	194	86	800	200	89	813	203	90
0.3750	1288	322	143	1360	340	151	1398	350	155
0.4375	1944	486	216	2112	528	235	2206	552	245
0.5000	2723	681	303	3063	766	340	3266	817	363
0.5625	3592	898	399	4209	1052	468	4602	1150	511
0.6250	4513	1128	501	5531	1383	615	6230	1558	692
0.6875	5447	1362	605	7004	1751	778	8163	2041	907

PLATE T	6×6×3/8			6×4×½			6×4×¾		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	171	43	19	174	44	19	176	44	20
0.2500	391	98	43	407	102	45	415	104	46
0.3125	717	179	80	773	193	86	805	201	89
0.3750	1137	284	126	1285	321	143	1374	344	153
0.4375	1619	405	180	1936	484	215	2148	537	239
0.5000	2125	531	236	2707	677	301	3139	785	349
0.5625	2620	655	291	3564	891	396	4354	1088	484
0.6250	3078	770	342	4469	1117	497	5785	1446	643
0.6875	3486	872	387	5384	1346	598	7415	1854	824

Table 7-4 — Allowable Grillage Weights For Soft Plate — Grillage With Simply Supported Spans— Bolt Chocks

(ALLOWABLE WEIGHT IN LBS.)

PLATE T	2×2×3/16			2×2×¼			2×2×3/8			2.5×2.5×3/8		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	175	44	19	176	44	20	176	44	20	176	44	20
0.2500	409	102	45	415	104	46	418	104	46	417	104	46
0.3125	783	196	87	803	201	89	814	203	90	811	203	90
0.3750	1312	328	146	1371	343	152	1401	350	156	1392	348	155
0.4375	2000	500	222	2138	535	238	2215	554	246	2191	548	243
0.5000	2832	708	315	3119	780	347	3284	821	365	3232	808	359
0.5625	3785	946	421	4315	1079	479	4637	1159	515	4534	1133	504
0.6250	4822	1205	536	5717	1429	635	6296	1574	700	6107	1527	679
0.6875	5904	1476	656	7304	1826	812	8276	2069	920	7953	1988	884

PLATE T	3×3×3/16			3×3×¼			3×3×3/8			2.5×2.5×3/8		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	172	43	19	175	44	19	176	44	20	176	44	20
0.2500	394	99	44	408	102	45	416	104	46	418	104	46
0.3125	729	182	81	779	195	87	807	202	90	813	203	90
0.3750	1167	292	130	1301	325	145	1380	345	153	1400	350	156
0.4375	1682	420	187	1973	493	219	2161	540	240	2210	553	246
0.5000	2234	559	248	2779	695	309	3167	792	352	3274	819	364
0.5625	2787	697	310	3690	923	410	4407	1102	490	4618	1154	513
0.6250	3312	828	368	4669	1167	519	5879	1470	653	6260	1565	696
0.6875	3789	947	421	5676	1419	631	7570	1892	841	8214	2054	913

PLATE T	4×4×3/8			4×4×½			4×4×¾		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	176	44	20	176	44	20	177	44	20
0.2500	413	103	46	416	104	46	418	105	46
0.3125	796	199	88	809	202	90	815	204	91
0.3750	1348	337	150	1386	347	154	1406	351	156
0.4375	2084	521	232	2176	544	242	2225	556	247
0.5000	3004	751	334	3200	800	356	3308	827	368
0.5625	4098	1025	455	4472	1118	497	4684	1171	520
0.6250	5342	1335	594	5995	1499	666	6383	1596	709
0.6875	6703	1676	745	7764	1941	863	8427	2107	936

PLATE T	6×6×3/8			6×4×½			6×4×¾		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	174	44	19	176	44	20	176	44	20
0.2500	404	101	45	413	103	46	417	104	46
0.3125	764	191	85	795	199	88	811	203	90
0.3750	1260	315	140	1346	336	150	1394	348	155
0.4375	1881	470	209	2079	520	231	2195	549	244
0.5000	2601	650	289	2995	749	333	3241	810	360
0.5625	3382	846	376	4080	1020	453	4553	1138	506
0.6250	4187	1047	465	5311	1328	590	6141	1535	682
0.6875	4979	1245	553	6654	1664	739	8010	2003	890

Table 7-5 — Allowable Grillage Weights For Soft Plate — Grillage With Simply Supported Spans— No Flange Bending

(ALLOWABLE WEIGHT IN LBS.)

PLATE T	2×2×3/16			2×2×¼			2×2×3/8			2.5×2.5×3/8		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	177	44	20	177	44	20	177	44	20	177	44	20
0.2500	419	105	47	419	105	47	419	105	47	419	105	47
0.3125	818	204	91	818	204	91	818	204	91	818	204	91
0.3750	1413	353	157	1413	353	157	1413	353	157	1413	353	157
0.4375	2244	561	249	2244	561	249	2244	561	249	2244	561	249
0.5000	3350	838	372	3350	838	372	3350	838	372	3350	838	372
0.5625	4770	1193	530	4770	1193	530	4770	1193	530	4770	1193	530
0.6250	6543	1636	727	6543	1636	727	6543	1636	727	6543	1636	727
0.6875	8709	2177	968	8709	2177	968	8709	2177	968	8709	2177	968

PLATE T	3×3×3/16			3×3×¼			3×3×3/8			2.5×2.5×3/8		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	177	44	20	177	44	20	177	44	20	177	44	20
0.2500	419	105	47	419	105	47	419	105	47	419	105	47
0.3125	818	204	91	818	204	91	818	204	91	818	204	91
0.3750	1413	353	157	1413	353	157	1413	353	157	1413	353	157
0.4375	2244	561	249	2244	561	249	2244	561	249	2244	561	249
0.5000	3350	838	372	3350	838	372	3350	838	372	3350	838	372
0.5625	4770	1193	530	4770	1193	530	4770	1193	530	4770	1193	530
0.6250	6543	1636	727	6543	1636	727	6543	1636	727	6543	1636	727
0.6875	8709	2177	968	8709	2177	968	8709	2177	968	8709	2177	968

PLATE T	4×4×3/8			4×4×½			4×4×¾		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	177	44	20	177	44	20	177	44	20
0.2500	419	105	47	419	105	47	419	105	47
0.3125	818	204	91	818	204	91	818	204	91
0.3750	1413	353	157	1413	353	157	1413	353	157
0.4375	2244	561	249	2244	561	249	2244	561	249
0.5000	3350	838	372	3350	838	372	3350	838	372
0.5625	4770	1193	530	4770	1193	530	4770	1193	530
0.6250	6543	1636	727	6543	1636	727	6543	1636	727
0.6875	8709	2177	968	8709	2177	968	8709	2177	968

PLATE T	6×6×3/8			6×4×½			6×4×¾		
	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5	E/H = 0.5	E/H = 1.0	E/H = 1.5
0.1875	177	44	20	177	44	20	177	44	20
0.2500	419	105	47	419	105	47	419	105	47
0.3125	818	204	91	818	204	91	818	204	91
0.3750	1413	353	157	1413	353	157	1413	353	157
0.4375	2244	561	249	2244	561	249	2244	561	249
0.5000	3350	838	372	3350	838	372	3350	838	372
0.5625	4770	1193	530	4770	1193	530	4770	1193	530
0.6250	6543	1636	727	6543	1636	727	6543	1636	727
0.6875	8709	2177	968	8709	2177	968	8709	2177	968

APPLICATION OF RESULTS

It is intended that a designer will be able to pick a proper grillage configuration and angle based on these curves, and, based on the soft plate curves, determine whether or not back up structure is necessary. The designer will begin this process with some preliminary information: the location of the equipment, the equipment’s weight, the equipment’s center of gravity, and the bolting pattern. With this information, he can determine from what structure the foundation can be hung (plating or stiffeners), he can calculate the e/h of the equipment (equipment center of gravity over the minimum orthogonal bolt spacing), and he can determine the preliminary flange condition (partially fixed at the heel, fully fixed at the heel, or no flange bending possible). Based on this information, the designer can determine the required angle size for his grillage. If the result of this initial check is unsatisfactory, the designer can then use these same design curves to reiterate the grillage to allow the use of a smaller angle size. The proposed process for designing a grillage is thus as follows.

GRILLAGES LANDING ON SHIP STRUCTURE

The first step in this process is to determine the location of the grillage spans and where the grillage ties into ship structure. If possible, especially with heavy equipments, it is desirable to land the grillage or its chocks on stiffeners as this avoids any potential need for back-up structure. Different equipment locations may result in a wide variety of configurations. A grillage may be cantilevered off of stiffeners, it may be simply supported between chocks, or it might contain multiple spans where one bolt lands on a grillage supported between stiffeners and another lands on a span cantilevered off of a stiffener. Whatever the case, in determining the angle size, it is important to use the worst configuration that exists for that particular grillage. Thus, it may be necessary to check both a simply supported span and a cantilevered span and use the most conservative angle size.

Once the preliminary grillage configuration is laid out, it is possible to determine the preliminary angle size using the e/h, flange condition, and length of the grillage span. If flange bending is possible, the condition at the heel of the angle (fully or partially fixed) can be determined from *Figure 7-1*. The length of span used should be the longest span on the grillage. The allowable curves can then be used to find the minimum angle size that is capable of carrying the equipment weight. It should be noted that these curves were generated based on a single span grillage and the allowable weights are therefore an allowable per span. Thus, with multiple span grillages where at least one bolt lands on each span, the weight of the equipment may be divided by the number of spans supporting the equipment when determining the required angle size. In doing this, the worst span should be used, based on length and configuration. A span is defined as two or more parallel angles bounded by common support points. If the resultant angle size is not desirable, the designer can modify the configuration by adding more spans, shortening the span length, or changing the flange bending condition in order to allow a smaller angle size to be used.

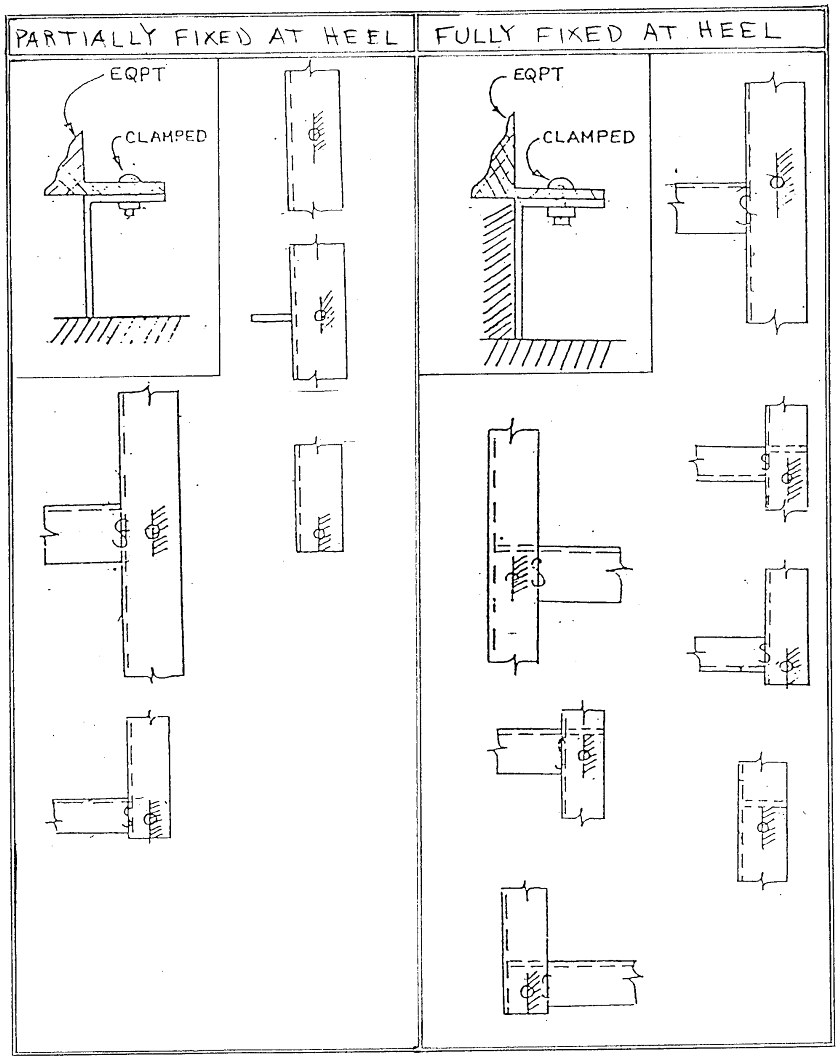


Figure 7-1 — Conditions of Flange Heel Fixity

GRILLAGES LANDING ON SOFT PLATE

A similar procedure is used in determining angle size for grillages landing on soft plate. In this instance it is necessary to check two sets of curves: one to determine the required angle size and one to determine whether back-up structure is required. First, the angle size is determined from the curves for simply supported spans using a length of span of zero. The simply supported curves are used since no grillage landing on soft plate should be cantilevered, and a length of zero is used because the purpose of landing on soft plate is to avoid unnecessary grillage structure so the bolts should land at the chock support. With the required angle size determined, the soft plate acceptability can then be checked.

The purpose of the soft plate curves is to determine whether or not it is acceptable to land a particular grillage on soft plate. For the equipment e/h, angle size used, flange bending condition at the heel and thickness of the soft plate, an allowable weight is determined. If this weight is greater than the equipment weight, then it is permissible to land the equipment on soft plate. If the allowable weight is less than the equipment weight, then back-up structure must be added or the grillage must be redesigned to tie-in directly with ship structure. As was the case for determining angle size, where multiple grillage spans exist, the equipment weight may be divided by the number of spans when checking the soft plate curves.

CONCLUSIONS AND RECOMMENDATIONS

The allowables determined from this analysis are extremely conservative. They use worst case bending, frequency, and flange configurations which produce relatively low allowables for the different angle sizes. If more variables were included as input to these curves, such as bolt spacing, actual bolt distance to the web and number of bolts, it would be possible to increase the weight allowed by a given angle size. The results of this would be longer spans, more grillages which could be cantilevered, and in general, less required welding and fitting for many grillages. However, this improvement would have to be weighed against the increased complexity for designers who would have to contend with determining these added variables and then sort through a larger set of curves to determine angle sizes. One possible solution to this dilemma is to replace the allowable curves with a set of design data sheets.

ROBOTICS FOR EQUIPMENT AND SYSTEM INSTALLATIONS

OBJECTIVE

Develop applications for robots to assist the installation of equipment and systems, especially portable robots consistent with constraints imposed by robotic operations, construction accuracy standards and candidate hull structure and outfitting details.

BACKGROUND / APPROACH

Robots may be constrained to those details where it is relatively easy to achieve the construction accuracy standards necessary to successfully employ robots. In order to be effective, structural geometry accuracy must be maintained to close tolerances, typically less than 1/16". However, it may be possible to broaden the use of robots through the use of standard construction details for both structure and outfit and especially equipment and system installation standards and to hold the manufacturing of these details to tolerances that can support the use of "teach" robots. The use of teachable/programmable robots would employ the use of "Teach Pendants" in association with 3-D vision and software programming for the selected standards..

The standards would be programmed with the use of a 3-D product model that would describe the tool path for the robot, whether a welder or other tool that would be utilized to install the quick attachment fasteners that may be used for equipment and systems. The resultant "MAP" would be used by the robots 3-D vision system to guide the robot. The Teach Pendant would provide the robot with the initiation and termination of the welding, drilling, or other operations sequence. The robot would compare the "standard" map of the weld/drilling/ops geometry with the 3-D vision of the actual weld/drilling/ops and make adjustments in the tool to account for differences (skewness and other characteristics) in order to complete the weld or other construction sequence.

The robot with "3-D" vision capability will sense the fabrication geometry and tool path based on the software map of the standard structural or outfit detail. The Teach pendant will orient the robot to its work and would both provide where the weld will be initiated and where it will be terminated. Since the tool path will be based on a standard, increased flexibility can be built into the software controlling the ability of the robot to respond to the differences between the 3-D perceived geometry and the standard map geometry.

Since even standard parts are not identical, the robot must be programmed to adjust to an ever-increasing tolerance range on the set of geometrical data for each standard. Identification of current state-of-the-art geometry constraints for robots should be developed in association with robot manufacturers. Improvement in the ability of robots to follow programmable tool paths for standard structural and outfit details and make adjustments for "actual" distortions, skewness, and irregularities will usher in advanced applications for robots.

TECHNICAL APPROACH

1. Identify Robotic operations, capabilities, limitations in following prescribed tool paths. Characterize state of the art in 3-D vision systems and teachable robots

2. Define parameters for the constraints on robots, standards, 3-D vision systems, and teach pendant systems.

3. Identify Candidate structural standards and outfitting system equipment and system installation standards and applications that would be amenable to be constructed with portable robots.

4. Select Candidate structural/outfitting details, portable robotic systems, 3-D vision systems, and teachable control systems to develop candidate applications for portable robotic systems.

5. Develop selected standards for portable robots using 3-D vision systems and teach pendants. Program software tool paths for the advanced portable robots using newly developed standards.

6. Develop demonstrations of portable robotics for candidate structural/ outfitting standards.

PIPE RUN NATURAL FREQUENCY ANALYSIS TABLES

STRAIGHT RUNS								
2.5G'S VERTICAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	21.62	AXIAL	29.7	2.1	29.2	20.4		
12 INCH STANDOFF		SHEAR	23.3	1.1	1.5	11.3		
4 INCH PIPE	17.70	AXIAL	244.0	116.0	197.0	144.0		
12 INCH STANDOFF		SHEAR	90.2	12.7	3.1	47.7		
12 INCH PIPE	3.43	AXIAL	2135.0	925.0	1590.0	1239.0		
12 INCH STANDOFF		SHEAR	109.6	16.5	42.2	59.4		

STRAIGHT RUNS								
2.5G'S VERTICAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	22.45	AXIAL	50.7	45.8	50.6	45.8		
12 INCH STANDOFF		SHEAR	12.1	0.0	0.0	5.8		
4 INCH PIPE	11.99	AXIAL	255.7	147.0	228.1	163.4		
12 INCH STANDOFF		SHEAR	93.3	8.5	18.8	47.5		
12 INCH PIPE	4.49	AXIAL	2143.0	957.9	1628.0	1256.0		
12 INCH STANDOFF		SHEAR	204.0	29.6	75.1	110.0		

STRAIGHT RUNS								
2.5G'S VERTICAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	22.47	AXIAL	88.9	91.2	88.8	91.3		
12 INCH STANDOFF		SHEAR	8.7	0.0	0.0	4.2		
4 INCH PIPE	11.19	AXIAL	293.3	192.8	266.9	208.5		
12 INCH STANDOFF		SHEAR	65.3	5.3	11.8	33.3		
12 INCH PIPE	4.54	AXIAL	2181.0	1004.0	1667.0	1301.0		
12 INCH STANDOFF		SHEAR	143.5	2.0	51.0	77.3		

PIPE RUNS WITH ELBOWS								
2.5G'S VERTICAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	15.09	AXIAL	28.9	19.4	28.7	19.5	29.2	20.4
12 INCH STANDOFF		SHEAR	0.0	0.0	17.7	0.0	3.0	10.6
4 INCH PIPE	9.11	AXIAL	222.5	131.9	232.8	128.7	194.9	148.4
12 INCH STANDOFF		SHEAR	8.7	0.0	7.4	6.8	34.2	46.0
12 INCH PIPE	1.52	AXIAL	1924.0	939.0	2178.0	957.0	1586.0	1253.0
12 INCH STANDOFF		SHEAR	35.1	7.5	115.4	10.9	49.8	54.7

PIPE RUNS WITH ELBOWS								
2.5G'S VERTICAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	16.9	AXIAL	49.9	36.2	49.9	46.1	50.6	45.9
12 INCH STANDOFF		SHEAR	0.0	0.0	9.2	0.0	0.0	5.4
4 INCH PIPE	12.45	AXIAL	241.2	142.5	242.9	153.7	227.2	165.5
12 INCH STANDOFF		SHEAR	61.3	3.7	71.0	2.5	24.7	45.1
12 INCH PIPE	2.24	AXIAL	1934.0	1012.0	2147.0	995.0	1620.0	1263.0
12 INCH STANDOFF		SHEAR	52.0	11.8	204.8	19.0	89.5	101.0

PIPE RUNS WITH ELBOWS								
2.5G'S VERTICAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	17.13	AXIAL	88.1	64.7	88.0	91.4	88.8	91.3
12 INCH STANDOFF		SHEAR	0.0	0.0	6.6	0.0	0.0	3.9
4 INCH PIPE	12.17	AXIAL	279.2	172.7	279.6	199.3	266.0	210.2
12 INCH STANDOFF		SHEAR	7.1	3.6	49.1	1.1	16.4	31.2
12 INCH PIPE	2.31	AXIAL	1968.0	1057.0	2170.0	1050.0	1657.0	1310.0
12 INCH STANDOFF		SHEAR	56.2	11.8	146.5	9.3	66.5	67.7

PIPE RUNS WITH VALVES								
2.5G'S VERTICAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	12.97	AXIAL	28.9	18.8	28.1	45.3	37.5	20.4
12 INCH STANDOFF		SHEAR	0.0	1.2	28.8	30.2	45.7	7.7
4 INCH PIPE	9.11	AXIAL	221.6	135.8	209.1	211.5	239.8	141.0
12 INCH STANDOFF		SHEAR	9.6	4.9	108.6	52.7	108.0	52.7
12 INCH PIPE	1.52	AXIAL	1923.0	956.0	2022.0	1457.0	1907.0	1152.0
12 INCH STANDOFF		SHEAR	41.2	9.0	159.0	53.2	121.0	67.2

PIPE RUNS WITH VALVES								
2.5G'S VERTICAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	13.43	AXIAL	49.9	36.1	49.7	70.5	58.5	45.8
12 INCH STANDOFF		SHEAR	0.0	0.0	14.2	15.4	23.0	3.6
4 INCH PIPE	12.45	AXIAL	241.5	141.6	226.6	232.9	265.1	160.1
12 INCH STANDOFF		SHEAR	5.8	4.5	97.5	54.7	108.5	48.6
12 INCH PIPE	2.24	AXIAL	1931.0	1035.0	1985.0	1498.0	1936.0	1194.0
12 INCH STANDOFF		SHEAR	59.8	14.2	281.3	99.1	223.3	122.8

PIPE RUNS WITH VALVES								
2.5G'S VERTICAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	13.44	AXIAL	88.1	64.6	87.9	115.8	96.7	91.3
12 INCH STANDOFF		SHEAR	0.0	0.0	9.6	10.6	15.7	2.4
4 INCH PIPE	12.16	AXIAL	278.9	171.3	263.6	278.4	303.5	204.8
12 INCH STANDOFF		SHEAR	6.7	4.2	66.4	37.1	73.9	33.5
12 INCH PIPE	2.31	AXIAL	1965.0	1083.0	2006.0	1553.0	1972.0	1241.0
12 INCH STANDOFF		SHEAR	64.7	14.3	199.5	64.3	159.9	82.4

STRAIGHT PIPE RUNS								
1.0G'S LATERAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	24.80	AXIAL	0.0	17.4	0.0	16.0		
12 INCH STANDOFF		SHEAR	12.3	2.1	1.1	0.9		
4 INCH PIPE	20.40	AXIAL	0.0	154.4	0.0	139.2		
12 INCH STANDOFF		SHEAR	82.8	17.4	30.1	13.4		
12 INCH PIPE	3.95	AXIAL	0.0	1602.0	0.0	1115.0		
12 INCH STANDOFF		SHEAR	498.6	66.4	21.9	66.0		

STRAIGHT PIPE RUNS								
1.0G'S LATERAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	25.82	AXIAL	0.0	33.5	0.0	29.0		
12 INCH STANDOFF		SHEAR	17.8	4.3	16.1	3.7		
4 INCH PIPE	13.79	AXIAL	0.0	203.5	0.0	148.5		
12 INCH STANDOFF		SHEAR	38.9	11.7	10.5	8.9		
12 INCH PIPE	5.16	AXIAL	0.0	1894.0	0.0	987.0		
12 INCH STANDOFF		SHEAR	279.1	33.0	50.5	32.6		

STRAIGHT PIPE RUNS								
1.0G'S LATERAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	25.84	AXIAL	0.0	55.9	0.0	50.0		
12 INCH STANDOFF		SHEAR	31.4	11.8	28.5	12.8		
4 INCH PIPE	12.87	AXIAL	0.0	236.1	0.0	168.0		
12 INCH STANDOFF		SHEAR	66.8	3.4	19.5	8.1		
12 INCH PIPE	5.22	AXIAL	0.0	1944.0	0.0	996.1		
12 INCH STANDOFF		SHEAR	273.4	15.9	39.7	14.7		

PIPE RUNS WITH ELBOWS								
1.0G'S LATERAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	17.35	AXIAL	0.8	1.8	0.7	17.0	0.0	16.0
12 INCH STANDOFF		SHEAR	9.9	0.6	7.3	1.3	10.6	0.8
4 INCH PIPE	10.48	AXIAL	2.3	62.3	33.5	146.5	2.9	122.6
12 INCH STANDOFF		SHEAR	38.5	82.9	24.3	6.1	8.9	11.8
12 INCH PIPE	1.75	AXIAL	20.0	591.0	248.6	1410.0	29.1	1022.0
12 INCH STANDOFF		SHEAR	490.2	789.2	25.4	19.9	5.8	27.9

PIPE RUNS WITH ELBOWS								
1.0G'S LATERAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	19.44	AXIAL	1.1	9.6	0.9	30.8	0.0	29.0
12 INCH STANDOFF		SHEAR	5.5	20.9	0.2	2.3	1.2	1.4
4 INCH PIPE	14.32	AXIAL	6.1	91.9	37.5	174.6	1.5	143.2
12 INCH STANDOFF		SHEAR	61.5	110.7	33.8	29.6	14.6	29.7
12 INCH PIPE	2.58	AXIAL	43.4	699.5	443.7	1580.0	48.4	1071.0
12 INCH STANDOFF		SHEAR	582.6	881.0	11.7	40.6	1.2	59.9

PIPE RUNS WITH ELBOWS								
1.0G'S LATERAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	19.70	AXIAL	88.1	64.7	88.0	91.4	88.8	91.3
12 INCH STANDOFF		SHEAR	0.6	0.0	0.6	14.8	0.0	14.9
4 INCH PIPE	13.99	AXIAL	279.2	172.9	279.6	199.3	266.0	210.2
12 INCH STANDOFF		SHEAR	7.1	3.6	49.1	1.1	16.4	31.2
12 INCH PIPE	2.66	AXIAL	1968.0	1057.0	2170.0	1050.0	1657.0	1310.0
12 INCH STANDOFF		SHEAR	56.2	11.8	146.5	9.3	66.5	67.7

PIPE RUNS WITH VALVES								
1.0G'S LATERAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	14.92	AXIAL	0.9	1.9	0.2	41.8	8.2	15.6
12 INCH STANDOFF		SHEAR	9.9	0.6	7.1	1.3	1.1	0.9
4 INCH PIPE	10.48	AXIAL	2.8	57.6	20.6	212.4	38.9	122.4
12 INCH STANDOFF		SHEAR	37.8	82.2	44.1	50.2	21.6	11.0
12 INCH PIPE	1.75	AXIAL	19.7	553.4	179.9	1765.0	262.9	102.0
12 INCH STANDOFF		SHEAR	486.4	771.5	50.9	41.8	23.6	26.2

PIPE RUNS WITH VALVES								
1.0G'S LATERAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	15.45	AXIAL	1.1	9.7	0.8	55.3	7.9	28.9
12 INCH STANDOFF		SHEAR	5.5	20.9	4.5	16.0	12.6	2.1
4 INCH PIPE	14.32	AXIAL	6.1	90.4	28.2	243.5	33.1	141.6
12 INCH STANDOFF		SHEAR	61.7	109.9	50.3	68.3	19.6	26.8
12 INCH PIPE	2.58	AXIAL	42.5	657.4	368.1	1837.0	278.4	1070.0
12 INCH STANDOFF		SHEAR	578.2	868.0	150.9	86.6	51.4	60.2

PIPE RUNS WITH VALVES								
1.0G'S LATERAL	**NAT. FREQ. (HZ)**	**LOADS (LBS.)**	**1**	**2**	**3**	**4**	**5**	**6**
1 INCH PIPE	15.46	AXIAL	88.1	64.6	87.9	115.8	96.7	91.3
12 INCH STANDOFF		SHEAR	0.5	0.4	9.6	10.6	15.7	2.4
4 INCH PIPE	12.16	AXIAL	278.9	171.3	263.6	278.4	303.5	204.8
12 INCH STANDOFF		SHEAR	6.7	4.2	66.4	37.1	73.9	33.5
12 INCH PIPE	2.31	AXIAL	1965.0	1083.0	2006.0	1553.0	1972.0	1241.0
12 INCH STANDOFF		SHEAR	64.7	14.3	199.5	64.3	159.9	82.4